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Mars Reconnaissance Orbiter 2005

Announcement of Opportunity

Proposal Information Package

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Table of Contents

1.0 INTRODUCTION....1-1
1.1 Purpose and Scope....1-1
1.2 Document Structure....1-1
1.3 Applicable Documents....1-1
1.3.1 JPL Documents....1-1
1.3.2 NASA Documents....1-1
1.3.3 Other Documents....1-1

2.0 GENERAL DESCRIPTION OF THE MISSION AND ORBITER....2-1
2.1 Mission....2-1
2.1.1 Reference Mission Synopsis....2-1
2.1.2 Reference Mission Phase Summary....2-2
2.1.3 Reference Mission Timeline....2-3
2.1.4 Reference Mission Phases....2-4
2.2 Orbiter....2-10

3.0 CONSTRAINTS IMPOSED BY MISSION AND ORBITER DESIGN....3-1
3.1 Payload Activities by Mission Phase....3-1
3.1.1 Launch....3-1
3.1.2 Cruise....3-1
3.1.3 Approach and Orbit Insertion....3-1
3.1.4 Aerobraking....3-1
3.1.5 Primary Science Phase....3-1
3.1.6 Relay....3-1
3.2 Resources Available for Payload Operations....3-2
3.2.1 Mass....3-2
3.2.2 Volume....3-2
3.2.3 Fields of View....3-3
3.2.4 Power....3-3
3.2.5 Instrument Pointing....3-4
3.2.6 Computational Resources....3-5
3.2.7 Data Return....3-5
3.2.8 Lifetime....3-5
3.3 Payload Interfaces....3-6
3.3.1 Configuration....3-6
3.3.2 Structural Interfaces....3-6
3.3.3 Thermal Interfaces....3-7
3.3.4 Data Interfaces....3-8
3.3.5 Command Interfaces....3-8
3.4 Orbiter Environments....3-8
3.5 Orbiter Environmental Tests....3-8
3.6 Payload Integration....3-9
3.6.1 Payload Integration Process and Control....3-9
3.6.2 Orbiter Integration and Test Flow....3-9
3.6.3 Launch Site Processing....3-11

4.0 MISSION OPERATIONS SYSTEMS....4-1
4.1 Ground Data System....4-1
4.1.1 GDS Architecture Description....4-1
4.1.2 Operational Downlink Data Flow....4-2
4.1.3 Operational Uplink Data Flow....4-3
4.1.4 Assembly, Test, and Launch Operations (ATLO) Data Flow....4-3
4.1.5 Ground Data System Constraints....4-3
4.1.6 SOPC Utilization....4-4
4.2 Operations System....4-4
4.2.1 Operations System Description....4-4
4.2.2 Pre-Launch Activities....4-4
4.2.3 Launch, Cruise, Approach, MOI, and Aerobraking Activities....4-5
4.2.4 Primary Science and Relay Phase Operations....4-5

5.0 MISSION ASSURANCE....5-1
5.1 Mission Assurance Plan....5-1
5.2 Review Plan....5-1
5.3 Risk Management Plan....5-1
5.4 Safety Plan....5-1
5.5 Configuration Management Plan....5-1

6.0 PAYLOAD MANAGEMENT....6-1
6.1 Roles and Responsibilities....6-1
6.1.1 Payload Manager....6-1
6.1.2 Project Scientist....6-2
6.1.3 Principal Investigator....6-2
6.1.4 Facility Science Team Leader / Team Members....6-3
6.2 Development Schedule....6-4
6.3 Reviews....6-5
6.3.1 Programmatic Reviews....6-5
6.3.2 Instrument Interface Meetings....6-6
6.4 Deliverables....6-7
6.4.1 Hardware....6-7
6.4.2 Software and Data....6-8
6.4.3 Documentation....6-9
6.5 Receivables....6-11

Appendix A - Acronyms....A-1

Appendix B – Subsurface Sounding Radar (SSR)....B-1
B.1 Overview of the Potential MRO Facility Radar Instrument....B-1
B.1.1 Instrument Rationale....B-1
B.1.2 Instrument Concept....B-1
B.2 Measurement Strategy....B-3
B.2.1 Measurement Modes....B-3
B.2.2 Data Sets and Acquisition Strategy....B-3

Appendix C – Engineering Subsystem Performance....C-1
C.1 Aerobraking Drag Pass Detection....C-1
C.1 Ultra Stable Oscillator (USO)....C-1

List of Figures

Figure 2.1.3.a	Reference Mission Timeline 1/3
Figure 2.1.3.b	Reference Mission Timeline 2/3
Figure 2.1.3.c	Reference Mission Timeline 3/3
Figure 2.1.4.a	Type 1 Interplanetary Transfer
Figure 2.1.4.b	Example Day in the Life (Candidate Science Payload)
Figure 2.1.4.c	Data Volume Capability
Figure 2.1.4.d	Variations in Apoapsis and Periapsis Altitudes and Periapsis Latitudes
Figure 2.2.a	Orbiter in Launch Configuration
Figure 2.2.b	Orbiter in Launch Configuration – Top View
Figure 2.2.c	Orbiter in Mapping Configuration
Figure 3.6.2.a	Example of Integration and System Test Flow
Figure 3.6.3.a	Example of Launch Site Sequence and Flow
Figure 4.1.1.a	Ground Data System Functional Architecture
Figure 6.2.a	MRO Project Development Schedule

List of Tables

Table 2.1.2.a	Reference Mission Phase Summary
Table 3.2.1.a	Mass Estimates for Selected Instruments
Table 3.2.2.a	Volume Estimates for Selected Instruments
Table 3.2.3.a	Fields of View for Selected Instruments
Table 3.2.4.a	Power Consumption for Selected Instruments
Table 3.2.5.a	Orbiter Pointing Accuracy
Table 3.2.5.b	Orbiter Pointing Stability
Table 3.3.2.a	Instrument Generated Dynamic Disturbances
Table 6.3.1.a	MRO Payload Review Schedule
Table 6.4.1.a	MRO Payload Hardware Delivery Schedule
Table 6.4.2.a	MRO Payload Software and Data Delivery Schedule
Table 6.4.3.a	MRO Payload Documentation Delivery Schedule
Table 6.5.a	MRO Payload Receivables Schedule

1.0 Introduction

This Proposal Information Package (PIP) is being supplied with the Announcement of Opportunity (AO) for the Mars Reconnaissance Orbiter (MRO) science investigations.

1.1 Purpose and Scope

The purpose of this document is to describe the MRO mission, orbiter, ground data system, and policies in sufficient detail to permit potential instrument providers to propose investigations that can be reasonably accommodated and are consistent with the project management and mission assurance philosophies.

Although this document is based on preliminary designs, it supplies potential payload providers and facility science teams the technical framework needed to propose viable payloads for MRO. Investigations should meet the technical and programmatic requirements described herein for the spacecraft and mission designs.

1.2 Document Structure

Section 1 provides an introduction to this document.

Section 2 provides a general overview of the mission and spacecraft.

Section 3 provides an assessment of the resources available to and the constraints imposed on the investigations by the reference mission and spacecraft designs.

Section 4 describes the ground data system (GDS) and mission operations activities.

Section 5 describes the mission assurance requirements levied upon the science payload.

Section 6 describes the payload management and deliverables for the orbiter instruments.

1.3 Applicable Documents

The following documents are applicable to developing MRO instrument hardware and software. Investigators may submit equivalent plans and processes for consideration by the MRO project office.

1.3.1 JPL Documents

D-5703	JPL Reliability Analyses Handbook
D-15378D	JPL Software Development Process Description
D-20241	MRO Environmental Requirements and Estimates
D-20327	MRO Project Mission Assurance Plan
D-20329	MRO Project Safety Plan
D-20380	MRO Project Risk Management Plan
D-20386	MRO Project Configuration Management Plan
D-20393	MRO Mission and Trajectory Description
D-20453	MRO Project Review Plan
D-20454	MRO Project Policies and Management Plan

1.3.2 NASA Documents

NASA-XXXX	Report of the NASA Science Definition Team for the Mars Reconnaissance Orbiter (MRO), February 9, 2001, ftp://spacescience.nasa.gov/announce/MRO_SDTreport.pdf

1.3.3 Other Documents

EWR 127-1	Eastern/Western Range Safety Regulations

2.0 GENERAL DESCRIPTION OF THE MISSION AND ORBITER

2.1 Mission

The Mars Reconnaissance Orbiter (MRO) mission will deliver a single orbiter (i.e., spacecraft plus science and engineering payloads) to Mars orbit which will conduct remote sensing science observations, including site characterization for future landed vehicles, and provide a telecom/navigation relay capability for follow-on missions. The mission will be designed to provide global access from a low altitude orbit that is consistent with (1) recovery of the Mars Climate Orbiter (MCO) science objectives using previously selected MCO investigations, (2) the potential provision by a mission partner organization of a subsurface sounding radar experiment, and (3) additional high-priority science investigations selected by the MRO Announcement of Opportunity (AO) process. A reference mission design has been prepared for the purpose of defining mission elements. Mission trade studies are ongoing and will be affected by programmatic needs, science priorities, risk, and constraints necessitated by the ongoing procurement of mission elements, notably the orbiter and launch vehicle.

2.1.1 Reference Mission Synopsis

The MRO orbiter will be launched and injected onto an interplanetary trajectory by an intermediate-class expendable launch vehicle (ELV). The launch and injection will occur during the Mars opportunity of August 2005. The transit to Mars will have a duration of approximately seven months. During the course of the mission, the orbiter will communicate with the Earth using NASA's Deep Space Network (DSN).

After arriving at Mars in March 2006, the MRO orbiter will be propulsively inserted into an initial, highly elliptical capture orbit with a period of approximately 35 hours. The orbiter will then use aerobraking techniques to supplement its onboard propulsive capability and reduce its orbit period to that necessary for the primary science phase (PSP). Following the completion of aerobraking, the MRO orbiter will perform a series of propulsive maneuvers to establish the primary science orbit (PSO). This orbit will have a minimum periapsis altitude near 200 km and an apoapsis altitude near 400 km. The PSO will be sun-synchronous with an ascending node orientation of 3:00 pm local mean solar time (LMST). During the PSP, repetitive (mapping) and targeted observations of the planet's surface and atmosphere will be conducted over a time span of one complete Martian year (687 Earth days), nominally from November 2006 through November 2008. Throughout the Primary Science Phase, the orbiter will have its scientific instruments nadir pointed for surface observations, except that the orbiter will have the capability to cross-track point up to 30 degrees from nadir a few times per day to observe off-nadir targets. During the primary science phase, science data acquisition will be planned such that data can be downlinked to the DSN during two 8-hour, 34-m tracking passes every day. During the Relay Phase, downlink to the DSN will be restricted to a single 8-hour, 34-m pass each day, thereby restricting the number of targeted sites and the overall science data volume that can be returned on a daily basis.

For short periods near the end of the Primary Science Phase and for similar periods throughout the Relay Phase, the MRO orbiter will support the Mars exploration program by providing approach navigation and relay communications support to various Mars landers and orbiters through its telecommunications/navigation subsystem. During these support periods, relay and navigation functions will have priority over orbiter science observations (including site characterization), although such observations may continue if they do not interfere and are within the mission resources. At all other times during the PSP, science observations will have priority, subject to the choice of targeted observations as described in the MRO AO. During the Relay Phase, relay and navigation support activities will have priority, followed by targeted observations to characterize future landing sites and then by additional science observations.

2.1.2 Reference Mission Phase Summary

Mission Phase	**Duration**	**Description**
Launch	Several Hours	Extends from the start of the launch countdown to the initial acquisition, by the DSN, of the orbiter in a safe and stable configuration.
Cruise	About Five Months	Extends from the end of the launch phase to two months prior to the Mars Orbit Insertion (MOI) maneuver. It includes initial checkout of the orbiter and its payloads, any calibration or validation activities needed to ensure expected performance in subsequent mission phases, and required trajectory correction maneuvers (TCMs).
Approach and Orbit Insertion	About Three Months	Extends from two months prior to MOI, through MOI, and until the orbiter is checked out and ready to begin aerobraking. The orbiter is inserted into a nearly polar orbit with a period of approximately 35 hours.
Aerobraking	Four to Six Months	Begins after Mars orbit insertion and on-orbit checkout and ends prior to the start of primary science. During this phase the orbiter's periapsis is lowered into the upper reaches of Mars' atmosphere. The apoapsis of its initial capture orbit is aerodynamically reduced to give an orbit period of about 2 hours.
Primary (mapping and targeting) Science (PSP)	Two Years	Begins after achieving the primary science orbit and continues for one Mars year (687 Earth days) after science instrument turn-on. This phase includes a relay/navigation support period late in the PSP to assist missions launched in 2007.
Relay	About Two Years	Begins at the conclusion of the PSP and continues until the end of calendar 2010. During this phase, the first priority is maintaining the orbiter as an asset to the Mars Exploration Program. Nominally, this gives priority to relay/navigation support to future missions arriving at Mars. If an extended mission is approved, second priority will be given to observations to define and characterize future landing sites and to additional science observations. Note that the downlink capability is reduced during this phase.

Table 2.1.2.a Reference Mission Phase Summary

2.1.3 Reference Mission Timeline

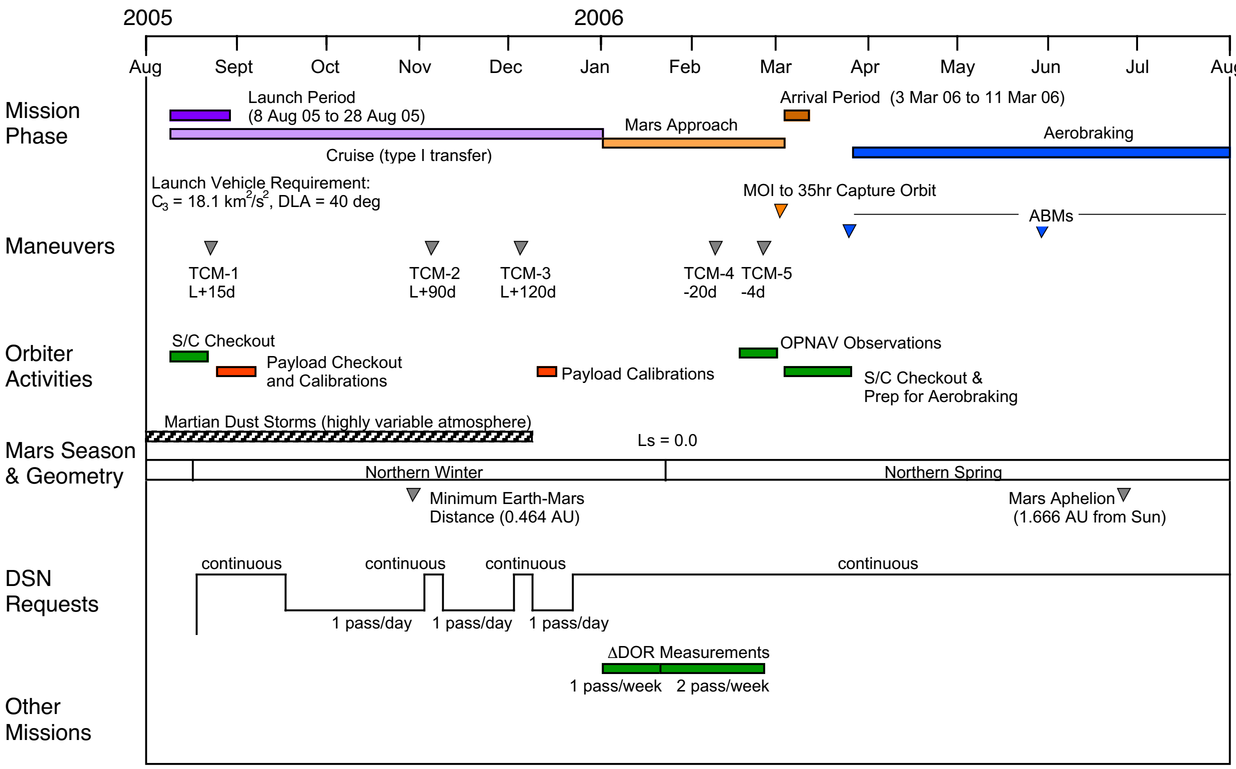

Figure 2.1.3.a Reference Mission Timeline 1/3

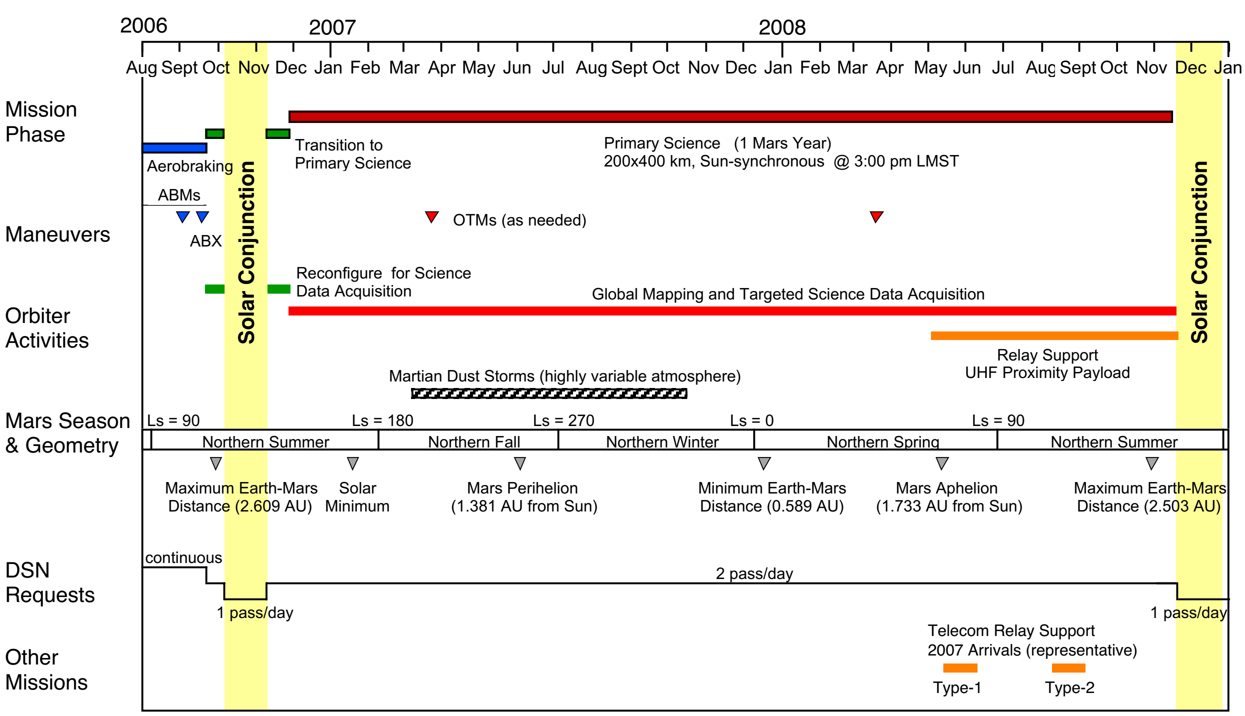

Figure 2.1.3.b Reference Mission Timeline 2/3

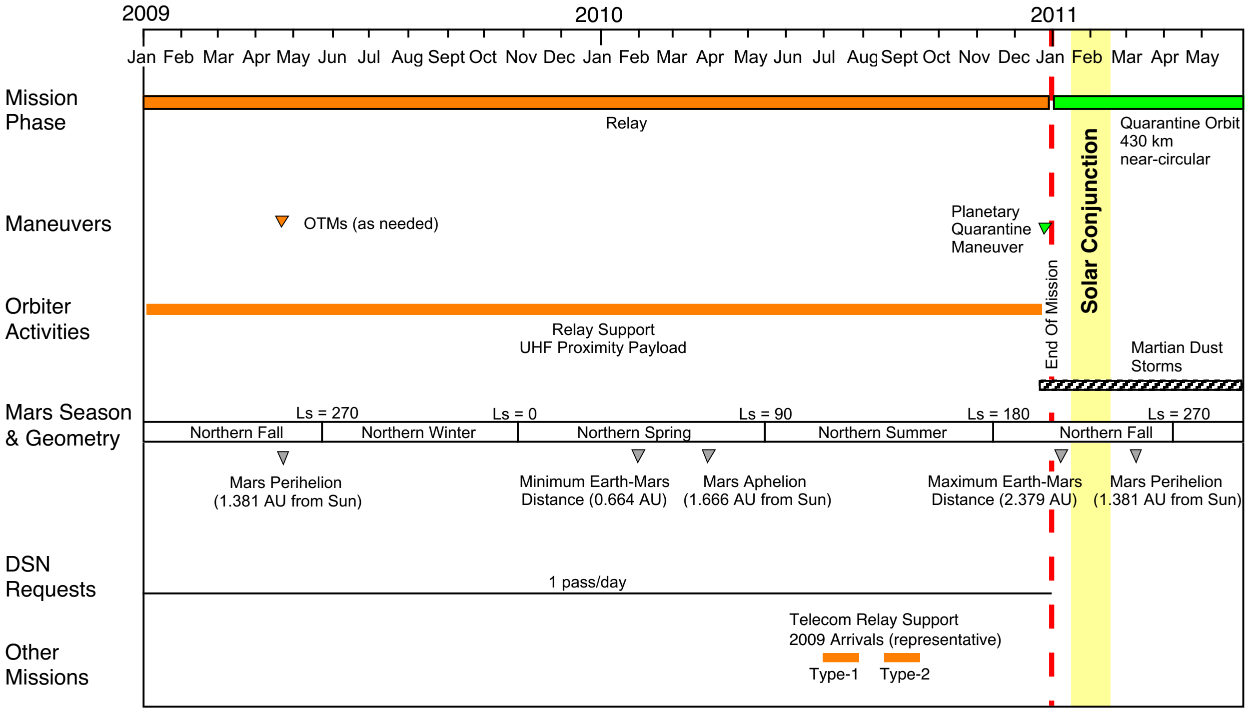

Figure 2.1.3.c Reference Mission Timeline 3/3

2.1.4 Reference Mission Phases

a. Launch Phase

Launch of the MRO orbiter will occur aboard an intermediate class expendable launch vehicle (ELV) from the Cape Canaveral Air Force Station in the late summer of 2005. The launch phase extends from the start of the launch countdown to the initial acquisition of the orbiter by the Deep Space Network (DSN). The reference launch period for the MRO mission is 21 days in length and extends from August 8 through August 28, 2005. This launch period provides Mars arrival dates between March 3 and March 11, 2006.

The launch phase extends from the start of the launch countdown to the initial acquisition, by the DSN, of the orbiter in a safe and stable configuration.

b. Cruise Phase

The cruise phase extends from the end of the launch phase to two months prior to the Mars Orbit Insertion (MOI) maneuver. It includes initial checkout of the orbiter and its payloads, any calibration or validation activities needed to ensure expected performance in subsequent mission phases, and the required trajectory correction maneuvers (TCMs).

A sketch of the interplanetary trajectory is presented below. This phase contains three of the five trajectory correction maneuvers to correct for injection errors and to precisely target the orbiter for delivery into Mars orbit.

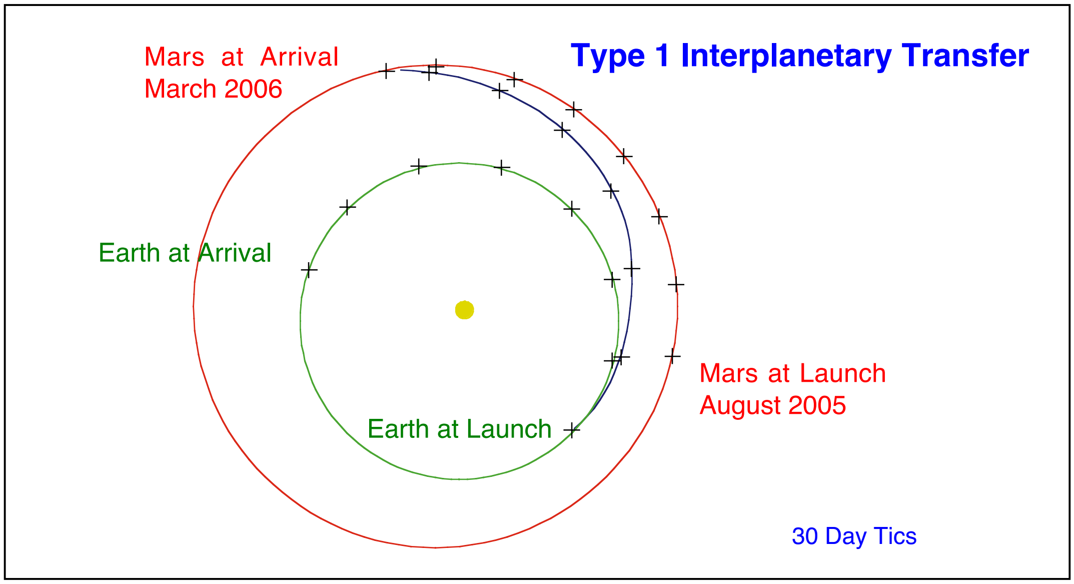

Figure 2.1.4.a Type 1 Interplanetary Transfer

c. Approach and Orbit Insertion Phase

The approach and orbit insertion phase extends from two months prior to MOI, through MOI, and until the orbiter is checked out and ready to begin aerobraking. During this phase, approach navigation will require increased DSN tracking. The final TCMs will be planned to target the spacecraft for its desired MOI on a southern approach trajectory. The Orbiter is inserted into a nearly polar orbit with a period of approximately 35 hours.

d. Aerobraking Phase

Aerobraking will consist of 3 distinct phases: a walk-in phase, a main phase, and a walk-out phase. During the walk-in phase, the orbiter establishes initial contact with the atmosphere as the periapsis altitude of the orbit is slowly lowered. This phase continues until the dynamic pressures and heating rate values required for main phase, or steady-state, aerobraking are established. During main phase, large scale orbit period reduction occurs as the orbiter is guided to dynamic pressure limits. Main phase continues until the orbit lifetime of the orbiter reaches 2 days. (Orbit lifetime is defined as the time it takes the apoapsis altitude of the orbit to decay to an altitude of 300 km.) When the orbit lifetime of the orbiter reaches 2 days, the aerobraking walk-out phase will begin. During the walk-out phase, the periapsis altitude of the orbit will be slowly increased as the 2 day orbit lifetime of the orbiter is maintained. Once the orbit of the orbiter reaches an apoapsis altitude of 450 km, the orbiter will terminate aerobraking by propulsively raising the periapsis of its orbit out of the atmosphere. Because the PSO has nodal orientation requirements, the aerobraking phase of the MSO mission must proceed in a timely manner and be completed near the time the desired nodal geometry is achieved.

e. Primary Science Phase

The reference MRO primary science phase (PSP) orbit is nominally 200 km by 400 km, sun-synchronous at approximately 3:00 pm local mean solar time (LMST) at the ascending node. No groundtrack grid control is expected for the MRO mission but some form of near-repeating groundtrack is assumed.

Data acquisition strategies have yet to be determined and will be developed as a result of the AO selection process. A representative data acquisition strategy is shown in Table 2.1.4.b, which depicts key relationships between assumed parameters for a reference payload, orbiter telecommunications and data system resources, and DSN resources.

Functionally, the observational modes of the reference science investigations fall into three categories:

1) Global monitoring throughout one Mars year (all seasons)
2) Regional surveys of Martian surface and subsurface
3) Targeted, high spatial resolution observations

The global monitoring instruments are the PMIRR Mk-II and the MARCI+ wide angle (WA) camera. The regional survey instruments are the subsurface sounding radar (SSR) and the MARCI+ medium angle (MA) camera, which also provides contextual information for the targeted observations. The targeted observation instruments are the High Resolution Imager (HRI) and the Visible-Near Infrared Imaging Spectrometer (VisNIR).

The global monitoring instruments are expected to require nadir pointing, low data rate, and operate most, if not all, of the time. These investigations are expected to use less than 10% of the expected downlink data volume at maximum range. The regional survey and targeted instruments are assumed to be high data rate instruments and will require precise targeting in along-track timing and cross-track pointing for short periods of time over selected portions of the surface. It is expected that more than 90% of the available downlink data volume will be used for regional and targeted investigations.

The orbiter will have a large data recorder (≥ 36 Gbits) and a high rate telecommunications capability (~280 kbps at maximum range). The time needed to downlink the full capacity of the data recorder varies from 3 days at maximum range to a fraction of a day at closer ranges. The orbiter is expected to be able to slew cross-track from nadir by as much as 30 degrees to point toward targets on the surface. Therefore, the possible number of targets under consideration for investigation varies considerably over the course of the mission.

Clear coordination and selection of target opportunities is very important for the control of operations cost and complexity. Because of navigation prediction accuracy considerations, it is expected that science sequences will be uplinked weekly, with more frequent timing adjustments as required. It is assumed that one to several months of targets will have been selected prior to being included in science sequences.

An example "day-in-the-life" of the orbiter during mapping is shown below in Figure 2.1.4.b. Global monitoring investigations are shown. HRI and VisNIR images are collected over similar and different targets. Due to the time needed for slewing and settling for each target, it is assumed that only two separate targets can be imaged in a given orbit. For targets along the same cross-track angle (or along nadir), the number of targets imaged is limited to available data storage. DSN coverage is shown with the currently assumed durations. High gain antenna (HGA) tracking is shown for the times when DSN is available. It is planned to schedule reaction wheel desaturation events during DSN tracking to increase navigation prediction accuracy.

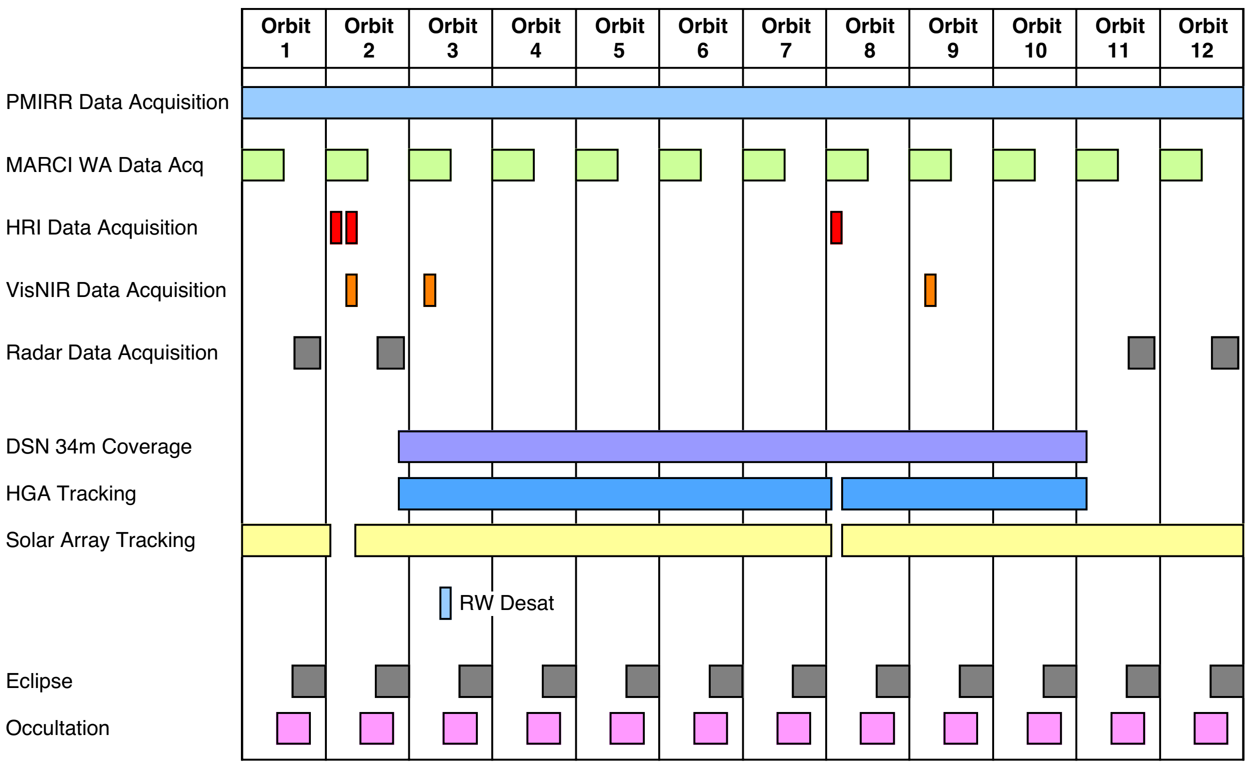

Figure 2.1.4.b Example Day in the Life (Candidate Science Payload)

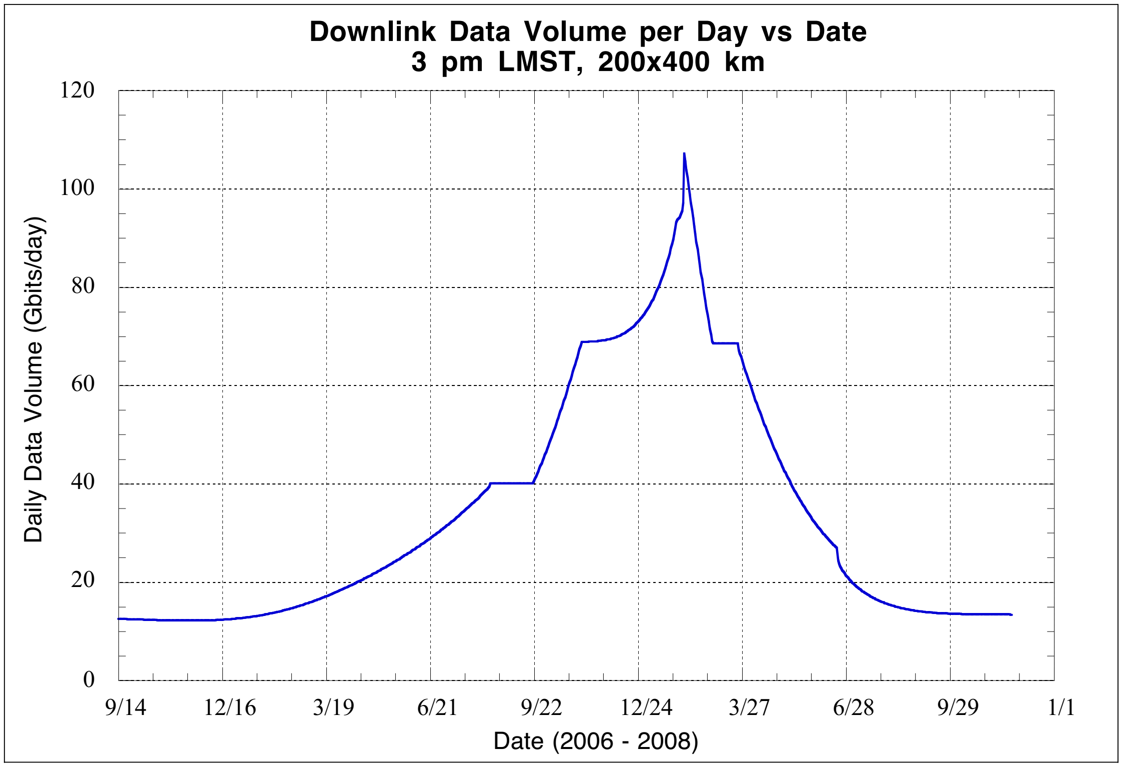

Figure 2.1.4.c Data Volume Capability

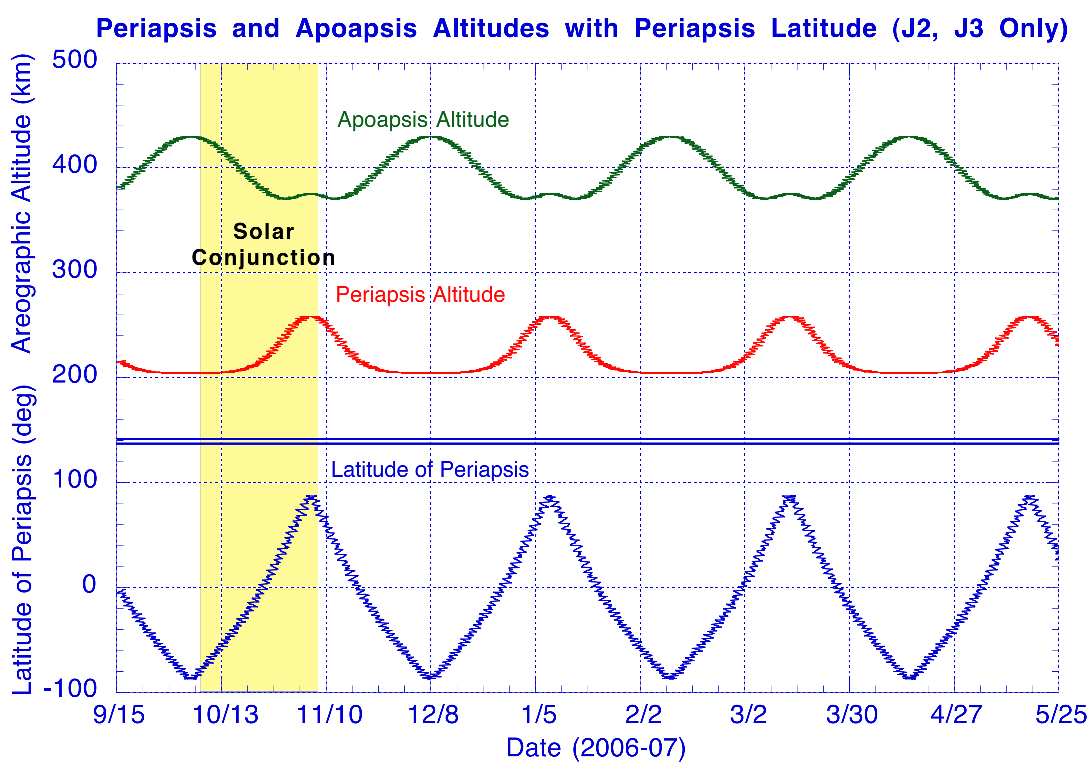

Figure 2.1.4.d Variations in Apoapsis and Periapsis Altitudes and Periapsis Latitudes

f. Relay Phase

The relay phase begins upon completion of the Primary Science Phase and continues until the end of calendar year 2010. During this phase, the orbiter will serve as a relay asset for navigation/communication support to the international Mars exploration program. This phase also has high potential for continuing science observation, giving priority to landing site characterization for future missions (e.g., '09 missions). Note that the downlink capability is reduced during the Relay Phase to a single, daily 8-hour pass to a 34-m DSN antenna.

After the December 2008 solar conjunction, the periapsis of the orbit will be raised to approximately 400 km. The specific date will be determined during the course of the mission. After periapsis is raised, the orbit will be adjusted to maintain the 3:00 pm LMST orbit orientation, subject to negotiation. At the end of the mission, the orbit will be raised to its planetary quarantine altitude.

Science operations will be conducted beyond the end of the MRO Primary Science Phase if approved by NASA.

2.2 Orbiter

The orbiter is being procured through a competitive selection in parallel with the AO process. Thus, the capabilities cited here are subject to change.

The orbiter will be designed to accommodate the selected science and engineering payloads for a launch in a 4-meter payload fairing. The maximum allowable injected mass for the reference launch date and trajectory is 1800 kg.

The orbiter will be fault tolerant and still operate within specification for 5.4 years. The orbiter attitude will be controlled in all 3 axes. X-band will be used to communicate with the ground. The orbiter will not include any radioisotope materials. The minimum downlink data rate at the maximum Earth range will be 280 kbps. Aerobraking, as well as a propulsion subsystem, will be used to implement the maneuvers necessary for cruise, orbit insertion, and orbit maintenance.

In addition to the science payload, the orbiter will accommodate a UHF navigation and communications package and an optical navigation camera. Instrument mounting and spacecraft pointing to enable instrument viewing in the nadir direction will be provided. Specific payload accommodate descriptions are included in Sections 3.2 and 3.3.

Following the detection of a fault condition or by ground command, the orbiter will be designed to enter a safe, and maintainable, configuration and attitude. The orbiter will issue a safing command to the payload and disable the payload prior to entering safe mode. During the fault, or during the entry into safe mode, an instrument can experience transient sun in its field of view (FOV).

Figures 2.2.a through 2.2.c present views of a reference orbiter in the launch and primary science orbit (PSO) configurations. Investigators are cautioned that these figures are for reference only and that the final orbiter is likely to appear and be configured differently.

Figure 2.2.a. Orbiter in Launch Configuration

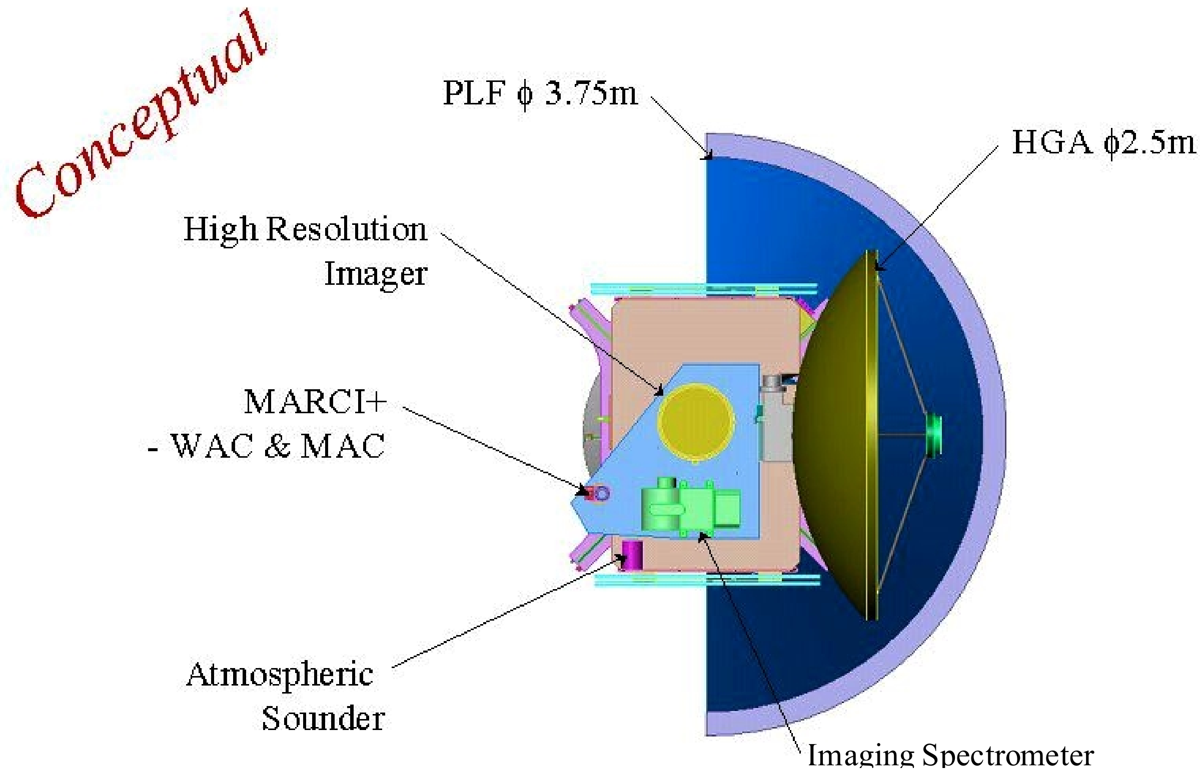

Figure 2.2.b. Orbiter in Launch Configuration – Top View

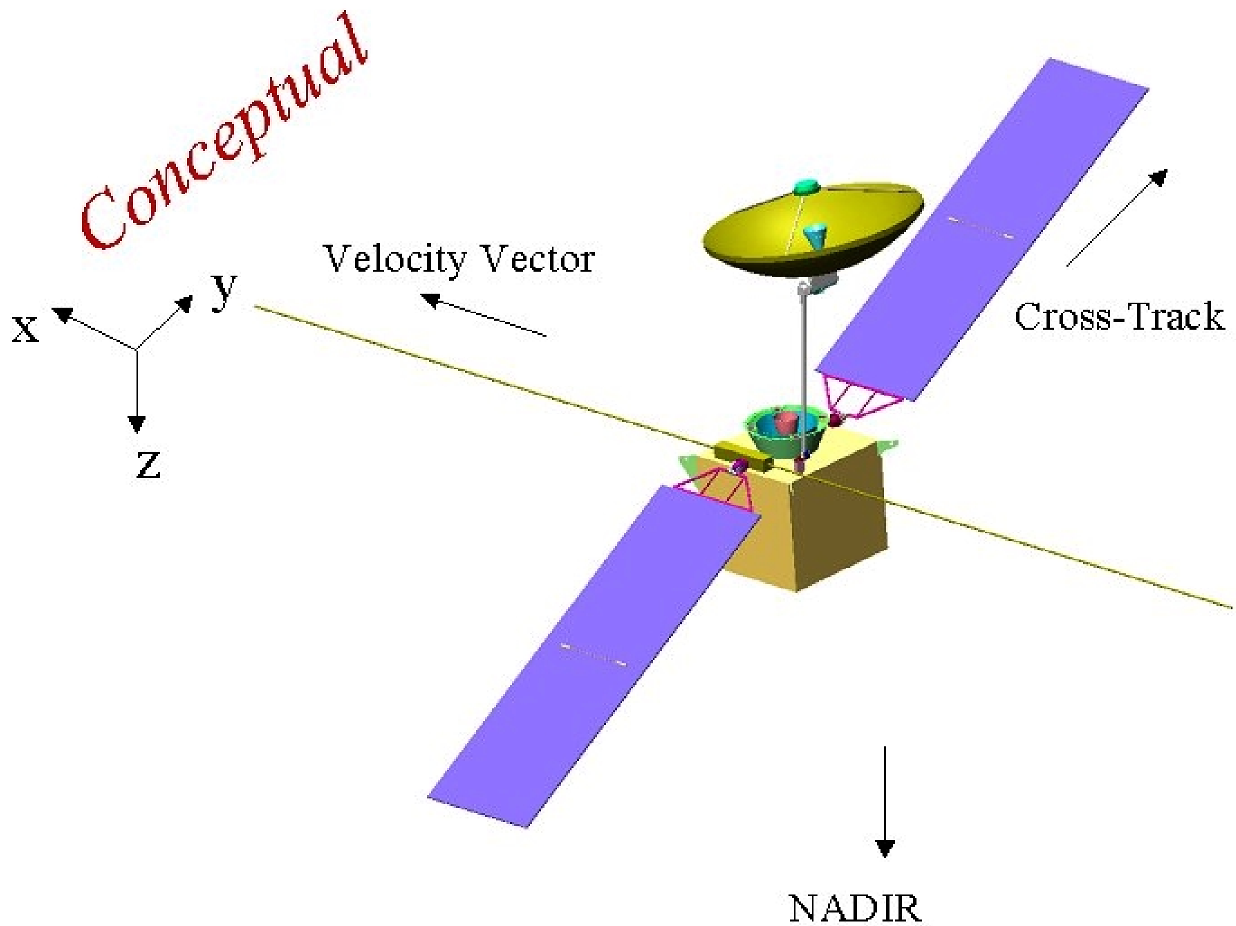

Figure 2.2.c. Orbiter in Mapping Configuration

3.0 CONSTRAINTS IMPOSED BY MISSION AND ORBITER DESIGN

3.1 Payload Activities by Mission Phase

3.1.1 Launch

The payload is launched in a powered off state.

3.1.2 Cruise

Opportunities will exist for health and safety checkout, deployments (if needed), and calibration observations. Actual dates and the scope of the checkout and calibration activities will be determined for each instrument based on its particular constraints. Requirements for calibrations should be justified in the AO response.

No instrument operation is expected for the first fourteen (14) days after launch, during trajectory correction maneuvers, within thirty (30) days of Mars orbit insertion, or during other critical orbiter events.

3.1.3 Approach and Orbit Insertion

No Mars approach science is expected. Limited calibration activities may be permitted in the MOI-60 days to MOI-30 days timeframe. Actual dates and the scope of the checkout and calibration activities will be determined for each instrument based on its particular constraints. Requirements for calibrations should be justified in the AO response.

3.1.4 Aerobraking

Aerobraking will take place over approximately 4-6 months, in a highly elliptical orbit with a period ranging from approximately 35 hours to roughly 2 hours. No science observations are planned during this period, except those directly required to support aerobraking activities.

3.1.5 Primary Science Phase

Mapping and targeted science observations are described in previous sections. Instruments will be expected to have the ability to operate simultaneously. The orbiter will be able to provide up to 30 degrees of cross-track pointing, by slewing the orbiter (i.e., no scan platform), up to twice per orbit. No along-track slew or nodding (with respect to nadir pointing) maneuver capability will be provided. All targeted observation requests will be coordinated with each other and with the available orbiter resources prior to the sequence planning process.

3.1.6 Relay

During the Relay phase, the orbiter will give priority to maintaining the orbiter as an asset to the international Mars exploration program. This gives first priority to relay/navigation support for future missions arriving at Mars. Additional observations by the science instruments may be approved by NASA as part of an extended mission, giving some emphasis to observations needed to define and characterize future landing sites and to seasonal observations limited during the PSP by relay support. Note that the downlink capability is limited during the Relay Phase to a single daily 8-hour pass to a 34-m DSN antenna, essentially reducing the volume of returned data by a factor of two when compared to the corresponding Earth-Mars distance in the PSP. This mission phase nominally extends to the end of 2010.

3.2 Resources Available for Science Payload Operations

3.2.1 Mass

The current best estimate (CBE) mass allocation for the reference science payload is 85 kg, based on the Project's current understanding of the orbiter and launch vehicle capabilities for the 2005 launch opportunity. Mass is a considered a critical resource for this mission.

Of this 85 kg, the MCO recovery investigations (PMIRR Mk-II and MARCI+) account for 10 kg. In addition, the facility subsurface sounding radar (SSR), potentially provided by a partner space organization, is allocated 12 kg (CBE). These values are shown below in Table 3.2.1.a.

Table 3.2.1.a Mass Estimates for Selected Instruments

Instrument	Mass
Atmospheric Sounder (PMIRR Mk-II)	7 kg
Wide/Medium Angle Camera (MARCI+)	3 kg
Subsurface Sounding Radar (SSR)	12 kg
Subtotal (Selected Investigations)	**22 kg**

The MRO SDT discussed a range of potential instrument configurations for this mission. For example, the MRO SDT suggested mass targets of 40 kg and 23 kg for the High Resolution Imager and Imaging Spectrometer, respectively [SDT Report, Appendix 3, Table A3-1]. No single instrument should use all, or nearly all, of the 63 kg allocation indicated here. In addition to the masses described above, the MRO Project is presently holding 30% mass margin on the science payload elements.

Investigators must propose CBE masses with recommended margins consistent with the instrument design maturity. When developing instrument proposals, mass estimates should include all payload equipment, e.g., electronics, MLI, caging mechanisms, booms, radiation shields, and interconnecting cabling between sensor and payload electronic boxes, as applicable. The orbiter will provide, and hold the mass for, mounting brackets, alignment cubes, and engineering temperature sensors.

3.2.2 Volume

Representative volumes for selected instrument are shown in Table 3.2.2.a.

Table 3.2.2.a Volume Estimates for Selected Instruments

Instrument	Maximum Dimensions (cm)
Atmospheric Sounder (PMIRR Mk-II)	30 x 30 cm (diameter x height)
Wide/Medium Angle Camera (MARCI+) Optics Electronics	 Ø 12 x 30 cm, Ø 5.5 x 7 cm 35 x 12 x 12 cm, 5.5 x 8.5 x 13 cm
Subsurface Sounding Radar (SSR) Receiver, Transmitter Dipole Antenna (stowed) Dipole Antenna (deployed)	 22 x 25 x 20 cm, 70 x 25 x 5 cm 45 x 25 x 10 cm 700 cm (tip-to-tip)

When developing instrument proposals, volume estimates should include all payload equipment, e.g., electronics, MLI, caging mechanisms, booms, radiation shields, and interconnecting cabling between sensor and payload electronic boxes, as applicable.

3.2.3 Fields of View

All science instruments, with the exception of the subsurface sounding radar (SSR), will be mounted on the science deck and provided views in the nominal nadir direction, allowing nested images to be obtained by the targeting instruments. Representative fields of view of the selected instruments are shown in Table 3.2.3.a.

Table 3.2.3.a Fields of View for Selected Instruments

Instrument	Field of View
Atmospheric Sounder (PMIRR Mk-II)	3.3 x 6.6 mrad, 80 deg half-angle, 2-axis articulation (conical)
Wide/Medium Angle Camera (MARCI+)	140° x 40° (WA), 6° cone (MA)
Subsurface Sounding Radar (SSR)	Omni-directional

Investigators should describe their instrument field of view (FOV) requirements and the impact on instrument performance of having small obstructions in that FOV.

3.2.4 Power

a. Power Conditioning

Payload power at payload connectors is unregulated 28Vdc (+8Vdc, -6Vdc).

b. Average Power and Peak Power

Orbital average power available to the science payload is 150 W. Cruise survival heater power available is 50 W. Cruise survival heater power is not available for supplemental heating of the instrument while the instrument is operating. Representative power consumption of selected instruments is shown in Table 3.2.4.a.

Table 3.2.4.a Power Consumption for Selected Instruments

Instrument	Operating	Cruise
Atmospheric Sounder (PMIRR Mk-II)	8 W average 15 W peak	8 W
Wide/Medium Angle Camera (MARCI+)	10 W average 12 W peak	6 W
Subsurface Sounding Radar (SSR)	50 W average 60 W peak	10 W
Subtotal (Selected Investigations)	**68 W average**	**24 W**

No power sub-allocation between the investigations solicited through the MRO AO has been attempted. However, no one instrument may use all, or nearly all, of the 82 W remaining in the allocation. Investigators must propose CBE power requirements and recommend margins consistent with the instrument design maturity. In addition to the CBE power allocations described, the MRO Project is presently holding 30% (50 kg) power margin on the payload science elements.

c. Power Switches

Each instrument will be allocated one single fault tolerant power switch to turn power on and off. A separate switch will be used for the replacement heater power circuits in the instrument.

d. Grounding

All instrument subsystem electronics should tie to a “star” ground tree. Ground trees will be negotiated with the orbiter contractor and documented in the interface control document.

3.2.5 Instrument Pointing

a. Pointing Accuracy

The orbiter will provide 3-axis pointing accuracy as shown in Table 3.2.5.a. Accuracy includes all error contributions between the true stellar reference and each instrument’s alignment reference. These accuracy requirements do not include ephemeris errors or target location errors.

Table 3.2.5.a Orbiter Pointing Accuracy

Parameter	Requirement (3 sigma)
Roll	< 0.7 mrad (140 arc-sec)
Pitch	< 1.0 mrad (200 arc-sec)
Yaw	< 1.0 mrad (200 arc-sec)

The orbiter will not re-point to build mosaics.

b. Pointing Stability

Stability requirements, as described in Table 3.2.5.b, will be met during science observations. Stability is relative to the instrument mounting reference. The orbiter is not required to meet the stability requirements during reaction wheel momentum desaturations, attitude slews, and during entrance into and exit out of solar eclipse.

Table 3.2.5.b Orbiter Pointing Stability

Stability (3 sigma, per axis)	
Duration	**Requirement**
2 minutes	< 0.0015 mrad (0.3 arc-sec) over 3 msec
5 minutes	< 0.05 mrad (10 arc-sec) over 100 msec
15 minutes	< 0.25 mrad (50 arc-sec) over 1 sec
Continuous	< 1.0 mrad (200 arc-sec) over 2 sec < 3.0 mrad (600 arc-sec) over 16 sec

3.2.6 Computational Resources

The orbiter provides the serial interfaces, discrete digital I/O, and mass memory to the science payload.

a. Orbiter Computer

The instruments will handle all their own computing. In addition, the proposer may also identify significant cost or resource savings if orbiter resources were used in place of instrument-provided capability. Use of orbiter resources (e.g., the spacecraft computer) may impose additional constraints on instrument testing and operation; these will be assessed once the spacecraft capabilities and the instrument requirements are defined. In any case, the proposal must provide the cost and identify the elements required for a self-contained instrument.

b. Volatile Memory

The orbiter will provide a minimum of 36 Gbits of volatile mass memory for use by the payload. To the extent practical the orbiter will avoid erasing stored science data as a result of responding to on-board faults. The orbiter will be capable of dynamically partitioning the payload memory based on the mission phase and the payload elements that are operating.

c. Non-Volatile Memory

The orbiter will provide 10 Mbytes of non-volatile memory for the entire payload. No single payload element may use all, or nearly all, of this shared resource. This memory space will be used for science code, control table, and observational sequence storage only. There will be no science data storage in this memory.

d. Transfer Rate to Mass Memory

The orbiter will support simultaneous, real time data transfers from all science payload elements to mass memory. The minimum effective data transfer rate will be 100 Mbps (up to 20 Mbps per instrument).

3.2.7 Data Return

A set of distinct data rates will be provided for the Primary Science and Relay Phases of the mission. Data rates will be selected, as a function of earth range, to maximize science data return for all orbiter instruments, together with required relayed lander and rover data.

The orbiter to Deep Space Network (DSN) maximum bit error rate (BER) is 1×10^{-5} for uplink and 1×10^{-6} for downlink

3.2.8 Lifetime

The science payload should be designed to operate within specification for 5.4 years.

3.3 Payload Interfaces

3.3.1 Configuration

a. Payload Mounting

The orbiter provides the payload mounting services, including the alignment cubes, which are mounted by the instrument provider. Instrument alignment tolerances and in-flight calibrations will be negotiated and documented in the instrument ICDs. The instruments will be aligned relative to the orbiter bus coordinate system with a control accuracy of 1 mrad per axis, 3 sigma, and a knowledge accuracy of 0.5 mrad per axis, 3 sigma.

b. Optics Covers

Optics covers are the responsibility of the payload provider. Note that the orbiter does not incorporate sun avoidance software during emergency operations. Instruments must provide their own protection against inadvertent sun viewing as required.

c. Cleanliness and Purge Distribution

Upon receipt by the orbiter integrator, the instruments will be maintained in a Class 100,000 clean room, with 45±5% relative humidity, and kept at a temperature of 20±5˚ C. Requests for additional nitrogen purge lines will be evaluated on a case-by-case basis.

d. Mechanical Closeouts

The orbiter mechanical closeouts are limited to safe and arm plugs. No additional closeouts are available to the payload. There will be limited electrical access to the orbiter, but not direct electrical access to the payload. Any non-flight instrument covers must be removed prior to payload fairing closeout, which may occur prior to transport to the launch pad.

e. Electrical Connectors

The orbiter contractor is responsible for providing both sides of the standard connectors, with appropriate connector savers, at the interface based on signed ICDs. Standard connectors are miniature “D” or micro ”D”. Use of other connector types will be considered on a case-by-case basis. Delivery dates will be negotiated to support instrument development.

3.3.2 Structural Interfaces

a. Launch Configuration Minimum Frequency

In the launch configuration, instruments should have a minimum natural frequency (fixed base) of 80 Hz. Lower frequencies must be approved by the MRO Project, which will require delivery of a sufficiently detailed dynamic model to be incorporated into the orbiter dynamic model in order to support coupled loads analyses.

b. Appendage Minimum Frequency

All deployed appendages must have a minimum natural frequency (fixed base) of 0.1 Hz.

c. Appendage Effective Mass

The mass moment of inertia of each deployed appendage must be less than 4 $kg\text{-}m^2$.

d. Instrument-Generated Dynamic Disturbances

Vibration disturbances induced by instruments due to their mechanical operation must not exceed the acceleration levels, measured at the instrument/spacecraft interface, given below in Table 3.3.2.a.

Table 3.3.2.a Instrument Generated Dynamic Disturbances

Frequency(Hz)	Acceleration, G (0-pk)
0.1 - 1	0.001
1 - 10	0.05
10 - 1000	0.1

3.3.3 Thermal Interfaces

a. Interface Constraints

Payload providers are responsible for developing a thermally isolated (conductive and radiative) interface between the instrument and the orbiter bus. The science deck should be assumed to have an effective surface emissivity of less than 0.1.

b. Payload Thermal Control Design

The payload provider is responsible for providing thermal control measures for maintaining required component temperatures independent of orbiter design. Thermal control hardware, including thermoelectric devices such as heaters or coolers, must be included in the mass, power, and volume budgets of the instrument.

c. Integrated Thermal Analysis

The orbiter contractor will conduct an integrated thermal analysis to ensure compatibility with the orbiter bus and other payload components. Payload providers will develop and deliver component-level thermal models to the orbiter contractor. Results of the integrated thermal analysis will be provided to the payload suppliers for refinement of the component level thermal analysis and design. The payload suppliers will be responsible for maintaining the more detailed interface thermal environments resulting from the integrated thermal analysis in their refined design.

d. Environment and System Testing

The orbiter contractor will perform system-level thermal vacuum testing. The orbiter will be tested in launch, cruise, and science orbit (without solar panels) configurations. Design thermal environments for launch, cruise, and on-orbit phases will be simulated with a combination of IR and solar lamps. For system-level testing, proto-flight test levels will be developed in accordance with strategy outlined in the MRO Environmental Estimates and Requirements document. Thermal qualification testing will be by the instrument provider before delivery of the instrument.

3.3.4 Data Interfaces

a. Standard Interfaces

Standard data interfaces are RS-422 and Low Voltage Differential Signaling (LVDS). The payload is expected to provide the interface circuitry based on signed interface control documents (ICDs).

1) The maximum science data throughput from the selected hi-speed instrument interfaces to volatile memory may be up to 20 Mbps effective on the high-speed LVDS line. The interface is a synchronous clock/data/enable interface with dedicated LVDS wire pairs for each signal.
2) The maximum science data throughput from the selected low-speed instrument interfaces to volatile memory may be up to 9600 bps on the low-speed RS-422 line. This interface is a 9600 bps Universal Asynchronous Receiver/Transmitter (UART) line.

b. Analog Interfaces

Each instrument is expected to provide status and housekeeping data for collection and formatting by the orbiter computer. Up to 4 analog temperature sensor channels can be provided to each instrument.

c. Digital Interfaces

The orbiter will provide two (2) programmable, general purpose, single ended digital input/output (I/O) channels for each instrument. The digital I/O logic levels will be 5-Volt Transistor-Transistor Logic (TTL) compatible.

d. Time Services

The orbiter will time tag payload data with an accuracy of ±30 msec relative to the orbiter clock.

The orbiter will distribute orbiter time once per second to any science instrument that requires it, with an accuracy of ± 1 msec.

A data word containing orbiter time will be distributed, as well as a 1 Hz time tick. At each time tick, the most recently distributed value of orbiter time will be valid.

3.3.5 Command Interfaces

a. Circuit Protocols

The orbiter provides synchronous clock/data/enable serial command interfaces utilizing RS-422 compatible devices. The payload is expected to provide the interface circuitry based on signed interface control documents (ICDs). Each RS-422 command interface only supports a single data clock rate of 500 kbps.

b. Command Storage

The orbiter will provide at least 2 Mbytes for payload element commands, plus timing information for each command

3.4 Orbiter Environments

Preliminary environment descriptions for all phases of the mission are described in the JPL reference document D-20241, “Preliminary Environmental Requirements and Estimates”.

3.5 Orbiter Environmental Tests

System-level orbiter environmental tests and margins are described in the JPL reference document D-20241, “Preliminary Environmental Requirements and Estimates”.

3.6 Payload Integration

This section describes the payload integration process. All hardware and software delivery dates are contained in Section 6.4.

3.6.1 Payload Integration Process and Control

A Payload Integration Working Group (PIWG) will be established soon after instrument selection. The orbiter team and the principal investigators (PIs) will mutually develop comprehensive, accurate, and traceable requirements for inclusion in the interface control document (ICD) for each instrument. The ICDs will cover mechanical, electrical, configuration, environments, software, facility support, etc. The payload interface is standardized with respect to electrical specifications (power, data, EMI, connectors, etc.). Any unusual instrument thermal, electrical, purge gas, or mechanical needs must be identified early, resolved, and documented in the ICDs. This includes special requirements such as on-orbit calibration, sensor stimulation, and contamination control.

3.6.2 Orbiter Integration and Test Flow

Science instruments are integrated with the orbiter after most orbiter engineering subsystems have been installed and operated**.** Facility support at the orbiter contractor's facility required for standalone and integrated operations will be specified in the ICD. The instrument supplier is responsible for all aspects of the stand-alone instrument verification prior to orbiter installation, including all instrument-unique test equipment, purge equipment, and sensor stimulators.

After arriving at the orbiter contractor's facility, the instrument (engineering model (EM) or Flight) is tested by the PI's instrument engineer using PI-provided ground support equipment (GSE). Throughout assembly, test, and launch operations (ATLO) the PI will be responsible for the analysis of all instrument data gathered during the system test activities and for providing any technical support personnel deemed necessary.

After installation on the orbiter (or orbiter testbed (OTB)), by the orbiter contractor, the instrument will be functionally tested under orbiter control with an instrument engineer present or on-line at a remote site. If required, nitrogen purge will be provided. Testing will be accomplished under documented control, including failure investigation, verification, and corrective validation testing.

Following installation of all instruments onto the orbiter, the instruments will be subjected to a series of system-level environmental tests, including acoustic, thermal vacuum, EMI/EMC, and pyroshock (a example test flow is shown in Figure 3.6.2.a).

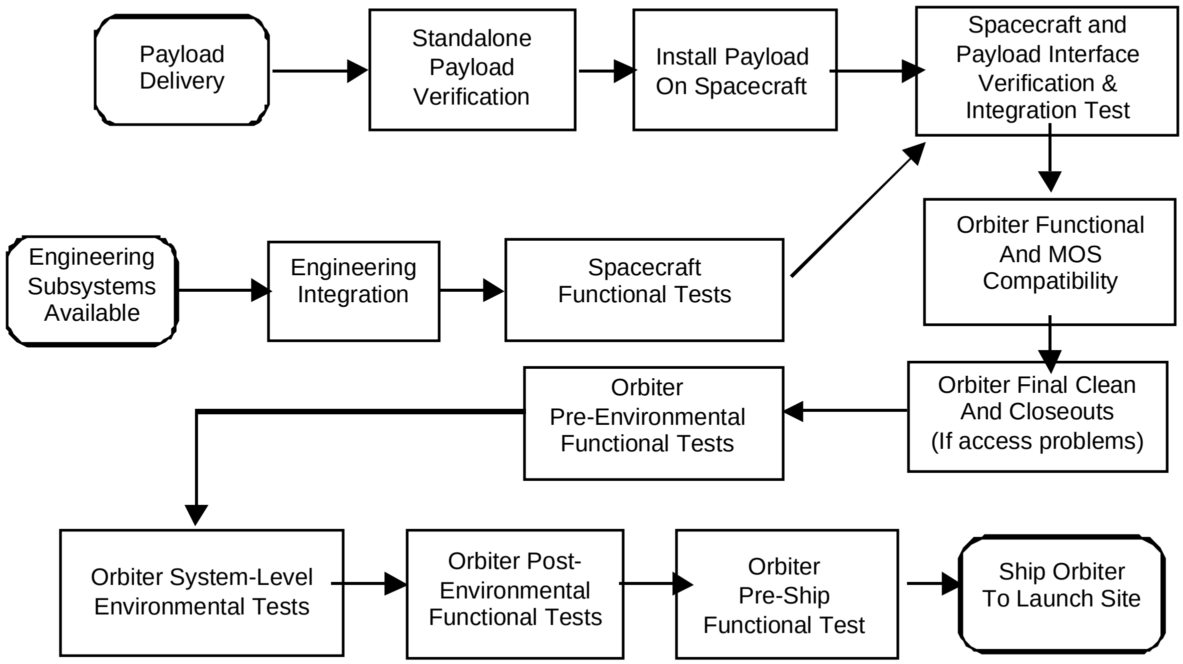

Figure 3.6.2.a Example of Integration and System Test Flow

In addition to system-level environmental tests, integrated system tests are conducted. These tests verify end-to-end mission critical events and functions using flight sequences.

In order to ensure mission success, payload functions, commanded through the orbiter bus, are also verified. PIs are required to provide sensor stimulators that will facilitate stimulation and response verification of instrument equipment and the orbiter (end-to-end mission function).

Upon completion of environmental tests, all alignments are revalidated. At various times throughout the test program, mandatory inspections are required by the PI to ensure that ICD configuration requirements are met.

Final cleaning and closeout for instruments that are not accessible when the orbiter is fully assembled are performed at the orbiter contractor's facility. There are no plans for subsequent removal of the instruments prior to launch.

3.6.3 Launch Site Processing

At the launch site, integrated system tests and final mission sequence testing will be conducted. An example of the flow is shown in Figure 3.6.3.a.

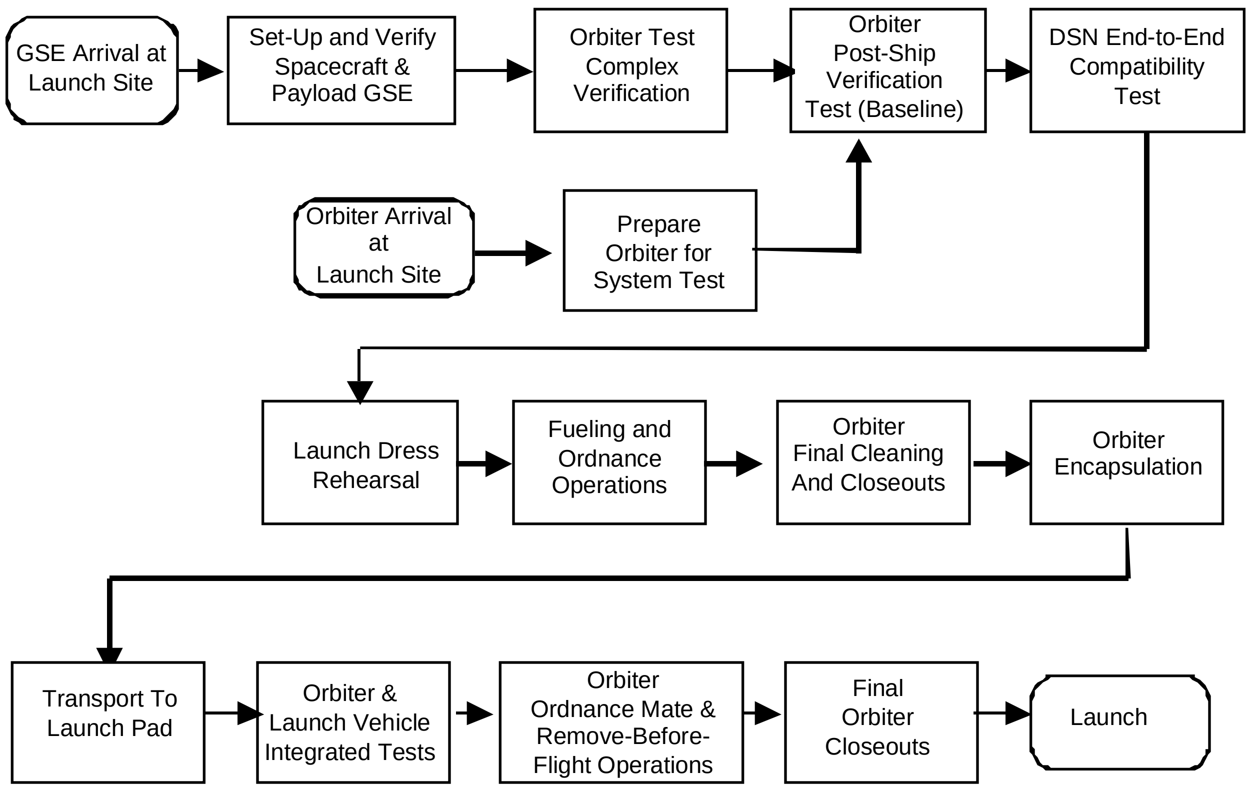

Figure 3.6.3.a Example of Launch Site Sequence and Flow

Final launch site tests are intended for launch readiness verification only. The instrument PI will be required to provide resources to support this testing. Orbiter ordnance installation, final blanket adjustment (and associated final cleaning and closeouts), and encapsulation (i.e., payload fairing installation) are performed at the launch site (launch payload processing facility) except where access prevents launch site cleaning. Scheduling final cleaning and closeout of instruments will be negotiated with each instrument team. In general, the schedule will be based on accessibility and impact on the orbiter /launch vehicle integration flow. The instrument supplier is responsible for providing any equipment required to support payload activity during launch site operations. In general, there is no access to or powered-on operation of the payload while on the launch pad.

4.0 MISSION OPERATIONS SYSTEMS

Mission Operations Systems consists of two parts:

1. The ground data system which provides the hardware, network and software.
2. The operations system which includes people and procedures.

Section 4.1 describes what the ground data system will include.

Section 4.2 describes what the operations system will include.

4.1 Ground Data System

4.1.1_GDS Architecture Description

The Ground Data System (GDS) utilizes the full resources of

a. JPL's institutional capabilities;
b. the Planetary Data System (PDS); and
c. project-specific resources, including PI resources,

for the purposes of supporting the following:

a. operations development;
b. mission operations;
c. data analysis;
d. data archive; and
e. data distribution.

Capabilities are phased to support different mission phases. Figure 4.1.1.a shows an overview of the ground data system functional architecture.

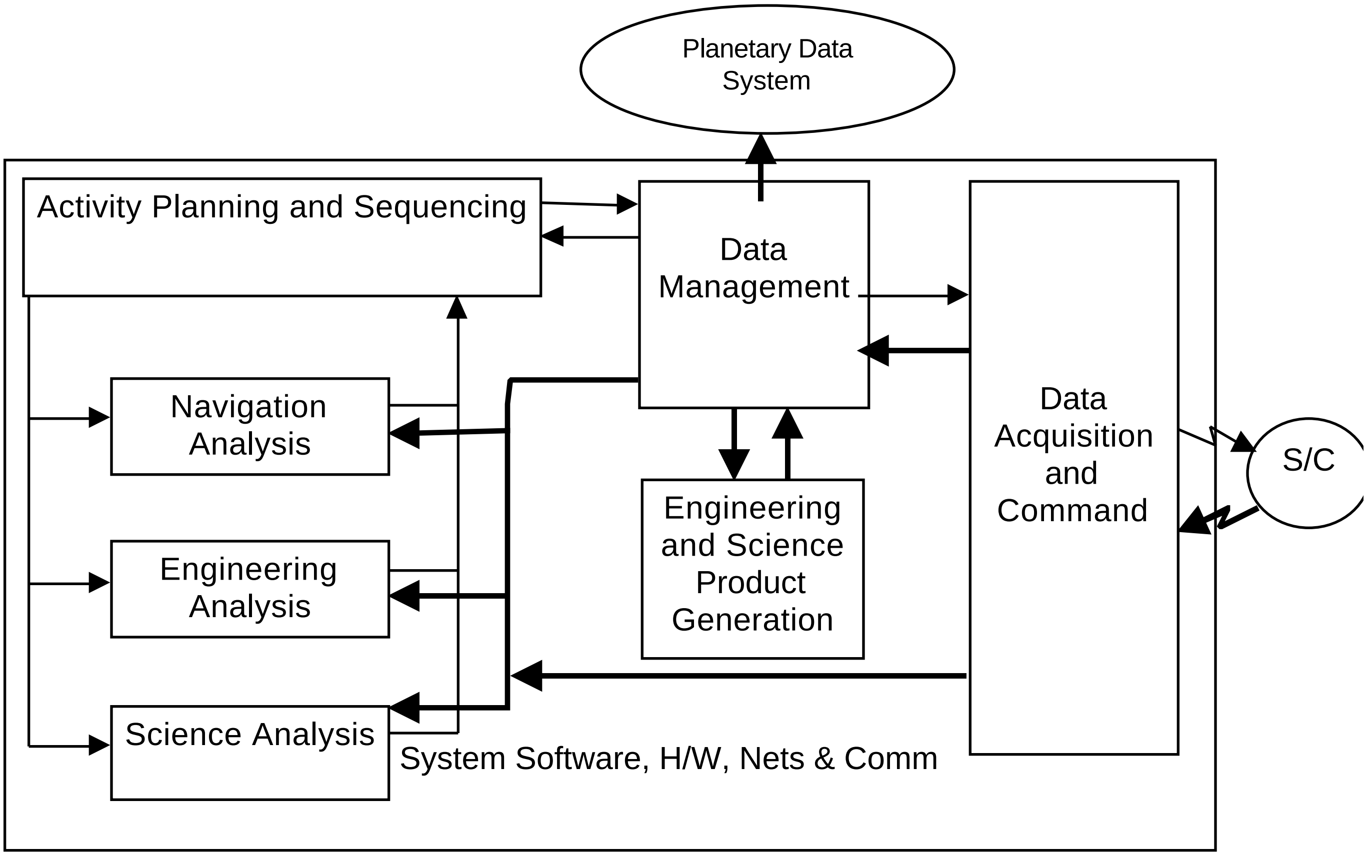

Figure 4.1.1.a Ground Data System Functional Architecture

4.1.2_Operational Downlink Data Flow

a. The Deep Space Network (DSN) acquires the orbiter data and navigation data (Doppler and ranging). Orbiter data and navigation data will be transferred from DSN stations to JPL for further processing.

b. The Telemetry System at JPL performs initial processing on telemetry frames and engineering packets. Telemetry processing includes frame synchronization, de-packetization, and engineering data channelization.

c. The Navigation Section at JPL performs initial processing of radiometric data and forwards the data to project navigators.

d. Processed channelized engineering data is broadcast in near real-time within the secured network environment. Channelized data display capability will be provided to perform channel processing that includes channel derivation, conversion, alarm checking, and display generation. Display types include plots, matrices, and lists. User will be able to define the content of display windows, subject to Project approval.

e. Orbiter and instruments engineering data, and a small subset of day to day operational related science data, will be stored in a database for near real-time and non-real-time access. These data will be pushed to offline storage after a certain period of time. Access to this off-line data will nominally take 24 hours after request is received.

f. Investigators must identify and cost in their proposals the facility (e.g., at the proposer's host institution) which will process all science data from the proposed investigation. The proposing investigator is also responsible for redistribution of the data to his/her science team (e.g., Co-Investigators and Collaborators) and for placing data products in the Planetary Data System (PDS). The data processing software will be the responsibility of the PI/TL, who should include all costs of software development and maintenance. Because of the large volumes of data expected from MRO, further studies during Phase A/B are required to determine the optimal strategy for handling the MRO data, particularly for the high data rate instruments.

g. Raw instrument data will be distributed via media to science team members by the MRO Project and to the PDS.

4.1.3_Operational Uplink Data Flow

a. Command request generation and validation: Instrument command requests will be generated by the PI using PI-developed software or JPL-delivered software and submitted to JPL for integration in a file format specified by JPL. The requesting PI team will validate command requests for correctness. Orbiter operators or navigators will generate orbiter command requests by using either contractor-developed or JPL-developed software. The orbiter operators will validate the commands.

b. Command requests integration and validation: Multiple instrument command requests and orbiter command requests will be integrated and validated by the orbiter simulator to ensure the orbiter and instrument health and safety. This validation is done by the orbiter operator.

c. Command radiation: Commands will be radiated through DSN antenna to the orbiter after validation and approval process is completed.

d. Storage, retrieval, and file exchange capabilities will be provided by the ground data system for operational file data including command related files. Each PI site will be provided access privileges. File data older than 6 months will be pushed to off-line storage.

e. Uplink related data files will be archived by the project.

4.1.4_Assembly Test and Launch Operations (ATLO) Data Flow

The command and telemetry commanding system used for ATLO will be compatible with the flight operation systems. The telemetry format and command format will be identical to the flight operations system.

During system tests, telemetry data will flow back to JPL ground data system, and the PI will be able to access some of the data via the Science Operations and Planning Computer (SOPC) mechanism.

4.1.5_Ground Data System Constraints

To minimize GDS development costs, proposers are encouraged to follow the constraints below:

a. On MRO, science data, engineering, or instrument health packets will use a channelization scheme, so that the instrument PI must: (1) not use internal channelization, (2) follow the data typing rules below, and (3) only switch channels based on packet id, orbiter clock value, or flag values.

b. The standard memory readout is a bus code of 8 bits, address of 32 bits, and values are an even number list of 8 bit bytes.

c. The standard data types are : 1-4 bit flags, 1-32 bit unsigned integers or collection of bits, 2-32 bit 2's complement signed integers, 32 or 64 bit IEEE floating point numbers, or 1-12 bytes of 8 bit ASCII characters.

d. Byte alignment and packing rules have the most significant byte first in a word, and the most significant word first in a long word.
e. The most significant bit in a field is bit 0.
f. The GDS will conduct transition once a year to maintain a level of compatibility with multi-mission system.

4.1.6_SOPC Utilization

A Science Operations and Planning Computer (SOPC) is provided to each science investigation. There will be a dedicated data line to connect from the investigator's site to JPL. The bandwidth of each data line will be determined based on the required science instrument data volume.

Many, but not all, of the JPL operational software will be loaded on the SOPC to support science operations. The primary functions of the SOPC are to

a. provide communication between science sites and JPL
b. allow for retrieval of engineering data and a subset of science telemetry and file data
c. allow for engineering data display
d. allow for command request packaging.

All applicable operational software will be installed, tested, and maintained by the GDS. In additions, all computer system administration activities will be maintained by GDS.

Science data processing operations may also use these dedicated SOPC as long as they do not jeopardize the above functions (a-d).

4.2 Operations System

4.2.1_Operations System Description

The operations system includes operations people and procedures utilizing the ground data systems described in the Section 4.1. The MRO operations system will be managed by JPL. These operations responsibilities are distributed among JPL, the orbiter contractor, and the principal investigators. Strategies, processes, and procedures developed to fly earlier Mars spacecraft will be modified and enhanced to meet the needs of the MRO mission.

4.2.2_Pre-Launch Activities

During pre-Launch phase, operations development activities will emphasis the following areas:

1. Orbiter and instruments operations concept development.
2. Orbiter and instruments operations scenario development
3. Orbiter and instrument operations processes and procedures development
4. Contingency planning and development
5. Participation in ATLO to test flight operations sequences and command, including commands and sequences generation, integration, testing, verification and validation
6. Plan and conduct operations training activities
7. Plan and conduct operations testing activities

The PIs will be involved in the development of nominal and mission critical sequences that involve payload functions to be tested in ATLO. Post-launch sequences necessary for payload health checks and in-flight calibrations will be developed, tested, and approved prior to Launch.

The PIs or their representatives will be participants in end-to-end information system tests and operations readiness tests, optionally from their remote sites.

4.2.3_Launch, Cruise, Approach, MOI, and Aerobraking Activities

All activities planned for the mission will be documented in the project Mission Plan (see also Sections 2.1 and 3.1). Any planned science operations during these phases of operation will be documented in the Mission Plan. Flight teams at JPL, the orbiter contractor site, and PI sites will jointly conduct these activities to carry out the mission.

4.2.4_Primary Science and Relay Phase Operations

The Mission Plan will document the baseline operations strategy during the Primary Science and Relay phase (see also Sections 2.1 and 3.1). Any deviations will be handled via change request process.

5.0 MISSION ASSURANCE

5.1 Mission Assurance Plan

In the reference document “MRO Mission Assurance Plan” (JPL D-20327), a JPL-developed strategy for ensuring mission success is discussed. Sections deal with the following topics.

- Reliability Assurance
- Electronic Parts Engineering
- Materials and Processes
- Hardware Quality Assurance
- Software Quality Assurance

5.2 Review Plan

The “MRO Project Review Plan” is available as JPL Document D-20453.

5.3 Risk Management Plan

The “MRO Project Risk Management Plan” is available as JPL Document D-20329.

5.4 Safety Plan

The “MRO Project Safety Plan” is available as JPL Document D-20380.

5.5 Configuration Management Plan

The “MRO Project Configuration Management Plan” is available as JPL Document D-20386.

6.0. PAYLOAD MANAGEMENT

This section describes the roles and responsibilities of key personnel in the successful development and conduct of science investigations for the MRO mission. Only those roles and responsibilities addressing payload management issues are addressed here. While each experiment provider is encouraged to utilize techniques that have proven successful on previous space missions, the following principles apply.

1. Consistent with applicable NASA Management Instructions, the Principal Investigators (PIs) bear the primary responsibility for ensuring that the instruments are designed and developed in a manner which will meet the objectives of the selected science investigations. The PIs must demonstrate to the Project that this responsibility has been fulfilled, as the Project will not attempt an independent verification that the detailed design and the performance requirements are compatible.
2. Project design control will focus on the interfaces of the instrument with the orbiter, operations, system-level test, launch vehicle safety, and mission design.
3. The Project shares with the PI the responsibility for the ensuring that the Mission Assurance (MA) aspects of the instrument development effort are consistent with both the mission duration and the expected environments. Consequently, the Project will assess the development effort to verify that the MA aspects of the PI's Project-approved Experiment Implementation Plan (EIP) are being implemented.
4. Each PI is fully responsible for ensuring that the selected investigations are implemented within the resource allocation existing at the time of MRO science confirmation, except as modified by written Project approval.

6.1. Roles and Responsibilities

Briefly, the MRO Project Manager is responsible for the overall MRO mission success, the Project Scientist for the scientific integrity of the MRO mission, the Payload Manager for payload development and integration with the spacecraft, and the Principal Investigator for the success of her/his experiment.

6.1.1 Payload Manager

The JPL Payload Manager provides payload contract management and is responsible for payload development, interface conformance of the instrument to the approved ICD, and delivery of the JPL-accepted government furnished equipment (GFE) payload for orbiter integration. Key functions of the JPL Payload Manager include, but are not limited to, the following:

1. Establish and approve the interface agreements between the payload elements and other systems, as part of the functional requirements and the design specification of the payload system.
2. Plan, direct, and control resources, schedule, risk, and performance commitments in fulfilling the payload system objectives.
3. Provide for the integration of the payload system with the orbiter, as appropriate.
4. Assure the quality, accuracy, and integrity of the technical documentation, including reports and other correspondence.

6.1.2 Project Scientist

The Project Scientist is responsible for the scientific integrity of the mission. The Project Scientist also represents the Scientific Investigators of the mission to the Project and to NASA. S/he also represents the Project, its Science Teams, and the Mission Science to the broader science community and to the general public. Key functions of the MRO Project Scientist include, but are not limited to, the following:

1. Make recommendations, as appropriate, to the MRO Project, the JPL Mars Exploration Directorate, and NASA Headquarters regarding changes in the MRO science objectives, including those of individual investigations.
2. With the NASA Program Scientist, chair the Project Science Group (PSG). Through the PSG the Project Scientist:
   - Adjudicates conflicts amongst the science investigations
   - Evaluates and make recommendations to the MRO Project regarding proposed modifications to mission design or instrument operations
   - Coordinates the choice of targets for off-nadir and special observation through the PSG's Target Acquisition Group (TAG)
   - Approves a Project Data Management Plan (PDMP) prior to data acquisition
3. Assure public dissemination of scientific results by the MRO Project and its science investigations through professional meetings, publications, and releases by the public affairs office, including active support of outreach activities.

6.1.3 Principal Investigator

The Principal Investigator (PI) is responsible for all aspects of the selected PI/Facility science investigation. These include the instrument design and development, fabrication, test and calibration, and delivery of flight hardware, software, and associated support equipment within project schedule and payload resources. The PI is also responsible for planning and support of the instrument operation, data analysis, and overall conduct of the investigation. Key functions of the Principal Investigator include, but are not limited to, the following:

1. Be the investigation's primary point of contact with other Project elements regarding investigation requirements, schedules, and funds. Represent the investigation in relevant Project reviews and meetings.
2. Generate and maintain documentation regarding the Investigation:
   - Experiment Implementation Plan (EIP)
   - Experiment Operations Plan (EOP)
   - Inputs to the Interface Control Document (ICD)
   - Investigation contribution to Project Data Management Plan (PDMP)
   - Other documents listed in Section 6.4.3
3. Ensure delivery and operation of an instrument able to achieve the investigation science objectives within mission resources, assuming nominal spacecraft operation:
   - Meet approved schedules and cost plans
   - Design, build, test, and calibrate the instrument appropriately
   - Design, build, test, and verify software and unique ground support equipment

- Support integration and test of the instrument at the orbiter contractor integration facility and at the launch site

4. Participate in the Project Science Group (PSG) meetings and associated working groups.
5. Support mission operations planning and execution, including:
   - Definition of mission database contents, including but not limited to, flight rules sequences, calibration data, telemetry, and commands
   - Integrated mission data/sequence development and flight software integration, using the orbiter test bed (OTB)
   - Operations test and training, including GDS and end-to-end tests
6. Conduct the instrument's operation consistent with the Mission Plan and the MRO Project resources, including:
   - Generation and validation of instrument commands, sub-sequences, and flight software modifications
   - Evaluation of the instrument's heath, safety, and performance in test and in flight
7. Ensure that the reduction, analysis, reporting, and archival of the results of the investigation meet with the highest scientific standards and completeness, consistent with budgetary and other recognized constraints.

6.1.4 Facility Science Team Leader / Team Members

The Facility Science Team Leader (TL) and Team Members (TMs) are responsible for planning and operational support of the facility hardware, data analysis, and the generation and archiving of data products. The Team Leader is responsible for the overall conduct of the investigation. Key functions of a Facility Team Leader and Team Members include, but are not limited to, the following:

1. Prepare for data analysis and timely product generation and archival.
2. Support mission operations planning and execution, including operations test and training.
3. Ensure that the reduction, analysis, reporting, and archival of the results of the investigation meet with the highest scientific standards and completeness, consistent with budgetary and other recognized constraints.

The Facility Science Team Leader has the following additional responsibilities:

1. Be the investigation's primary point of contact with other Project elements. Represent the Facility Science Investigation in relevant Project reviews and meetings, including in the Project Science Group (PSG).
2. Generate and maintain documentation regarding the Investigation
   - Experiment Implementation and Operations Plans (EIP/EOP)
   - Investigation contribution to Project Data Management Plan (PDMP).
3. Meet approved schedules and cost plans for the team.

6.2. Development Schedule

Figure 6.2.a illustrates the MRO master payload schedule, including payload deliverables in the context of the overall project schedule.

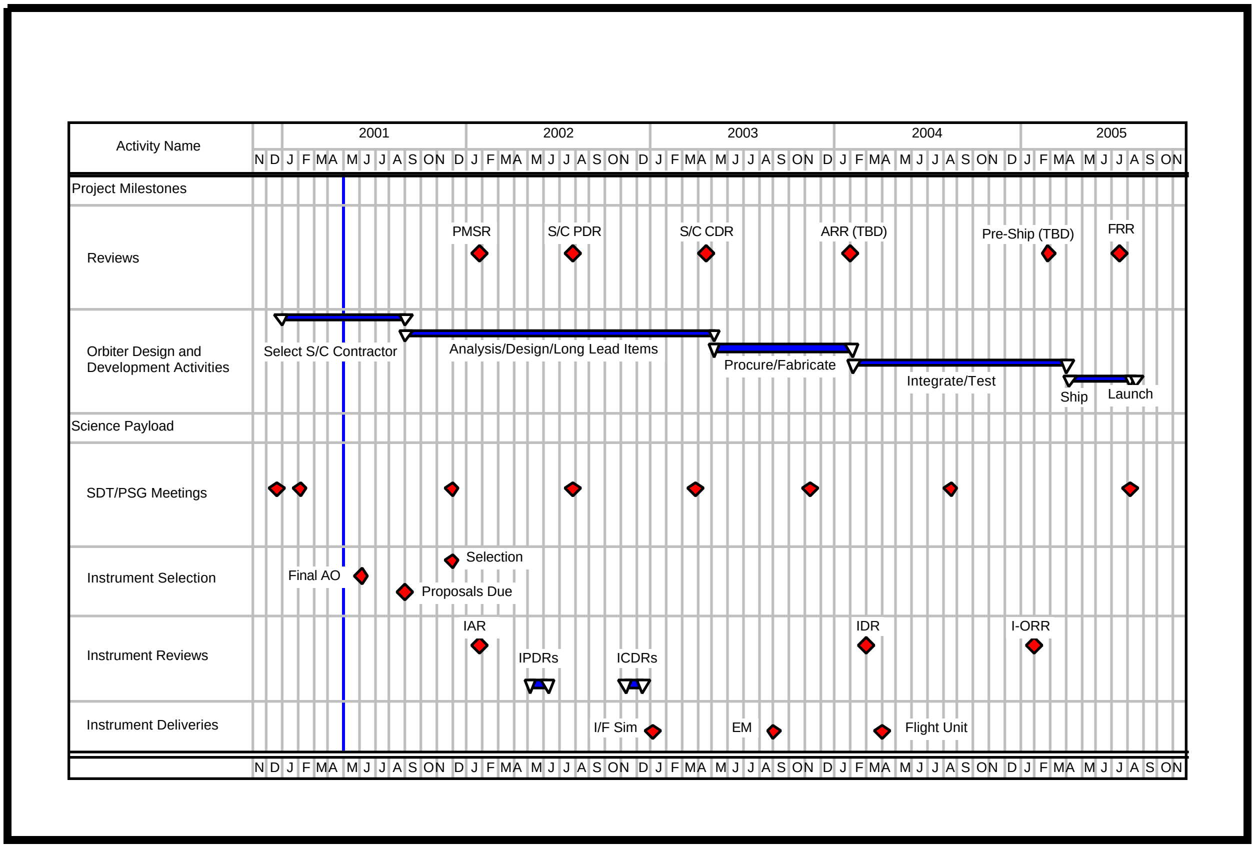

Figure 6.2.a MRO Project Development Schedule

6.3. Reviews

The payload PIs (or their designates) will be expected to attend and support, as needed, orbiter design reviews, ground system reviews, and occasional informal reviews scheduled by the project with instrument issues and/or presentations to be made by the PI or representative.

6.3.1 Programmatic Reviews

The MRO Project Review Plan (JPL D-20453) discusses in detail the form and function of the programmatic reviews. In general, the instrument design reviews precede the project design reviews.

a. Monthly Management Reviews (MMRs)

Monthly management reviews of programmatic, financial, and technical status will be held at the instrument provider's site. Major topics to be addressed are:

- Progress during past reporting period vs. plan
- Discussion of activities not accomplished
- Brief discussion of problems and concerns
- Schedule status and variance from baseline discussion
- Cost discussion, including comparison of actual and planned cost and an explanation of any variances
- Technical/design status, major technical issues, and problem/failure report status
- Implementation progress, including procurement and subcontract status

b. Instrument Accommodation Review (IAR)

Shortly after the science payload tentative selection, each investigation that includes hardware will begin preliminary design activities and prepare to support the instrument accommodation review (IAR) which will be held at the orbiter contractor's site. The purpose of the IAR is to establish the instrument's compatibility with the selected orbiter and to establish a firm commitment from the instrument provider of the Project-supplied resources (including, but not limited to, mass, power, volume, and fields of view) to conduct their investigation. The final negotiated commitment will be used by the Project to assess the overall payload needs and as the basis for recommending the confirmed payload to NASA at the Confirmation Reviews (CRs) held by NASA.

c. Instrument Preliminary Design Review (I-PDR)

The instrument provider will hold an instrument preliminary design review (I-PDR) at the hardware developer's location. This review will allow the Project insight into the progress being made in the instrument design and comparing that to the performance and estimated margins. The findings will be reported at the project preliminary design review (PDR).

The functional requirements document (FRD) and the preliminary interface control document (ICD) are presented at the PDR, with the instrument provider in a supporting role. Topics include discussion of the FRD, description of interfaces, and interactions between other instruments competing for shared orbiter resources. The FRD goes under formal change control at this time.

d. Instrument Critical Design Review (I-CDR)

The last design review prior to initiating flight hardware fabrication is the instrument critical design review (I-CDR). The I-CDR precedes the project critical design review (CDR) at the completion of the payload detail design. Topics include status of hardware design, fabrication, test, and calibration, software design and test plans, plans for integration, description of support equipment, finalization of interfaces, command and telemetry requirements, and discussion of environmental and system tests. The findings will be reported at the project CDR.

The orbiter-instrument interface control document (ICD) is presented at the CDR, with the PI in a supporting role. The ICD goes under formal change control less than thirty (30) days after this review is completed.

e. Instrument Delivery Review (IDR)

Lastly, the instrument provider will conduct an Instrument Delivery Review (IDR). This review is held just prior to instrument delivery to the orbiter contractor. Topics include how well the instrument complies with the FRD and the ICD, the results of environmental testing, and the completeness of the end item data package (EIDP).

f. Instrument Operations Readiness Review (I-ORR)

An instrument operations readiness review (I-ORR) will be conducted for each investigation team to assure interface compatibility between the mission operations system and the investigating team and to assess the operations readiness of the science team. This review is scheduled to occur about six months before launch and will focus on the operations environment, including hardware and facility readiness, a walk-through of the uplink planning and downlink analysis process and capability, and a review of the status of data analysis software.

These reviews, and additional project-level reviews that the PI are expected to support, are shown in Table 6.3.1.a.

Table 6.3.1.a MRO Payload Review Schedule

EVENT	DESCRIPTION	HOST	EVENT DATE OR DUE DATE
Payload Selection	…………………………………		Nov 01
MMRs	Monthly Management Reviews	PI	Monthly
Kickoff	…………………………………	Orbiter	Selection+1 mo
IAR (support)	Instrument Accommodation Review	Orbiter	Selection+3 mo
I-PDR	Instrument Preliminary Design Review	PI	Jun 02
I-CDR	Instrument Critical Design Review	PI	Nov 02
IDR	Instrument Delivery Review	PI	Mar 04
I-ORR	Instrument Operations Readiness Review	PI	Feb 05

6.3.2 Instrument Interface Meetings

A series of meetings will be scheduled to work out interface issues and document the design in the interface control documents (ICDs). The orbiter contractor will host the initial “Kick-Off” meeting. It is likely that the instrument interface meetings (IIMs) that follow will become “virtual” meetings, with the instrument provider support by a combination of conference calls and e-mails.

These are not formal reviews, but rather technical (only) interface meetings between the instrument provider engineers, the orbiter engineers, and the JPL instrument interface engineers. The initial focus will be on hardware and software interface issues, but will transition into resource sub-allocation discussions and operational strategies as the launch date approaches.

6.4. Deliverables

In the following sections, Tables 6.4.1.a, 6.4.2.a, and 6.4.3.a identify preliminary payload delivery dates. As described in the following sections, the instrument providers must, while meeting schedule and cost, do the following:

1. Shortly after selection, sign a memorandum of agreement (MOA) or contract, as applicable, with the project documenting resource allocations.
2. Provide and maintain required documentation (see Section 6.4.3)
3. Support the development and maintenance of ICDs.
4. Provide monthly technical progress reports (TPRs) and monthly financial management reports (FMRs).
5. Deliver a fit check template (transfer tool), an analytical thermal model, and a payload interface simulator to the orbiter contractor.
6. Deliver an engineering model that represents the form, fit, and function of the flight unit; negotiate any deviations with JPL and the orbiter contractor.
7. Deliver flight hardware (including thermal blankets if required) to the orbiter contractor with suitable shipping containers and any protective covers required.
8. Provide necessary instrument-unique payload Ground Support Equipment (GSE) for stand-alone integration, and launch operations.
9. Provide an instrument end item data package (EIDP), as described in Section 6.4.3.
10. Provide timely information (see Table 6.4.2.a) to establish and maintain controlled baselines for software interfaces, shared computational resources, mission data and mission operations timelines and sequences.

6.4.1 Hardware

The instruments must be accompanied by all ground support equipment (GSE) needed to support system test including optical and/or thermal targets. An end item data package (EIDP) must accompany the flight hardware. The fit-check template, interface simulator, engineering model, and flight unit delivery schedule is shown in Table 6.4.1.a.

Table 6.4.1.a MRO Payload Hardware Delivery Schedule

EVENT OR DELIVERABLE ITEM	DESCRIPTION	EVENT DATE OR DUE DATE
Payload Fit Check Template	Mechanical Interfaces..............	Dec 02
Payload Interface Simulator	Electrical and Protocol Tests.......	Feb 03
Engineering Model (EM) & GSE	Supports OTB Integration..........	Sep 03
Flight Unit & GSE	Supports Flight Integration.........	Apr 04

a. Payload Fit Check Template

The Payload Fit Check Template is used to verify the instrument mechanical interfaces with the orbiter. Specific details will be negotiated with the orbiter contractor and documented in the ICD.

b. Payload Interface Simulator

The Payload Interface Simulator is a ground support equipment (GSE) unit that allows for early verification of electrical (power, command, and data) interfaces, timing, and protocols. This unit may be used with the orbiter testbed (OTB) or developmental orbiter hardware. It must be functionally identical to the flight unit.

c. Engineering Model (EM)

The Engineering Model (EM) will be integrated into the OTB. The EM must also be capable of interface testing with the flight orbiter during ATLO. Any GSE needed to maintain the health of the EM in this environment (e.g., cooling) must be provided. The EM must provide electrical, timing, and protocol interfaces that are identical to the flight instrument, be capable of being stimulated to provide operational data, and be compatible with a clean room environment. The EM must also be capable of providing data sets that can be used to exercise the MOS/GDS. It is not required for this unit to be capable of being mounted on the flight orbiter or surviving environmental tests. This unit will remain with the OTB during mission operations and will not be returned until the science mission is complete.

d. Flight Unit

The Flight Unit must meet all the requirements contained in the FRD and ICD and will be integrated with the flight orbiter. The accompanying GSE must contain all hardware and software required for maintaining the health of the flight unit and providing for stimulation and testing.

6.4.2 Software and Data

Instrument software and data delivery dates are shown in Table 6.4.2.a.

Table 6.4.2.a MRO Payload Software and Data Delivery Schedule

EVENT OR DELIVERABLE ITEM	DESCRIPTION	EVENT DATE OR DUE DATE
Telemetry Calibration Data • Preliminary • Final	Definition of Instrument Telemetry Calibration Curves, Algorithms, and Tolerances	 I-CDR IDR
Flight Sequences • Preliminary • Final	Definition of Instrument Sequences for Use in System Test to Include All Instrument Operations Modes	 I-CDR IDR
Analytic Thermal Model • Preliminary • Final	Used to develop the system-level thermal design and support the thermal vacuum test	 I-CDR IDR
Initial Flight S/W and supporting documentation	Provide the initial FSW load to support OTB I&T	IDR
Initial Ground Software and supporting documentation	Provide the initial ground software to support system tests	IDR
Final S/W Baseline and supporting documentation	Provide the final FSW load to support flight ATLO	I-ORR
Final Ground Software and supporting documentation	Provide the final ground operations and data analysis software to support launch	ORR-1 Month

a. Software Documentation

Planning, requirements, design, build, test, and verification information that provides insight into the software implementation should be provided as they become available, in accordance with the PI’s normal development plan.

b. OTB Operations: Required Evaluation Procedures

To support the orbiter contractor's orbiter test bed (OTB) activities, test procedures are required from the payload provider and are subject to Project approval. The fidelity of the procedure and level of approval corresponds to the potential risks involved in the procedure.

c. Software Source Materials

The mission load (all executable orbiter and payload flight software and data) is generated as an integrated load image, including initial/nominal values for all updatable mission data/system files. To develop the mission load, source code for compilation, materials for binding, and the data/file load shall be provided in a timely fashion to support software development integration in the OTB, assembly and integration tests during science payload integration, and mission readiness tests at the launch site.

The delivery of ground operations and data analysis software should include source code, executable, compilation, executable generation instructions, and test files as well as any supporting documentation required to properly use the software.

6.4.3 Documentation

Instrument documentation delivery dates are shown in Table 6.4.3.a.

Table 6.4.3.a MRO Payload Documentation Delivery Schedule

DOCUMENT	DESCRIPTION	EVENT DATE OR DUE DATE
MOA/Contract	Memorandum of Agreement	Selection+1 mo
EIP	Experiment Implementation Plan	Selection+3 mo
FRD/Safety	Functional Requirements Document	Selection+4 mo
Flight Rules and Constraints • Preliminary • Final	Definition of Instrument Operation Constraints and Requirements	 I-PDR I-CDR
Command Telemetry Data • Preliminary • Final	Dictionary of Instrument Commands and Operations Modes; Definition of Instrument Telemetry Parameters	 I-CDR IDR
ICDs • Preliminary • Final	Inputs to Interface Control Documents	 PDR CDR
GDS/MOS Requirements • Preliminary • Final	Inputs to Ground Data System and Mission Operations System Requirement Documents	 IDR ORR – 1 month
P/L Handling Requirements • Preliminary • Final	Payload Handling Requirements List	 I-CDR IDR – 1 month
Unit History Log Books		IDR
End Item Data Package (EIDP)		IDR

a. Memorandum of Agreement (MOA) / Contract

Shortly after payload selection, the project will enter into an agreement with each instrument provider for the implementation of the selected proposal. Each agreement will document the instrument resource allocation (mass, power, volume and fiscal resources) and schedule between the project and the PI (and PI organization). The agreement will take the form of a contract for non-government entities, and a memorandum of agreement (MOA) for government entities.

b. Experiment Implementation Plan (EIP)

An experiment implementation plan (EIP) is required from all payload providers. An outline of the EIP follows:

1. Personnel
2. Project Interface
3. Instrument Fabrication, Test, Calibration, and Operations Development Plans
    - Schedule
    - Subcontracts
    - Hardware and Software Development
    - Operations and Data Analysis Development
    - Facility and Interface Development
    - Environmental Testing
    - Mission Assurance
    - Configuration Management and Control
    - Calibration
    - Cost Control / Earned Value Reporting (if contract is above $20M)
4. Requirements for JPL Support and JPL-Supplied Hardware
5. Requirements for Science Team Support and Data Analysis
6. Safety
7. Cost Plan

c. Functional Requirements Document (FRD) / Safety

The PI is responsible for writing the instrument functional requirements document (FRD), subject to Project approval, and supplying the necessary payload safety information to the orbiter contractor for the range safety plan and the payload safety reviews at the launch site.

d. Interface Control Documents (ICDs)

Interface control documents (ICDs) are negotiated directly with the orbiter contractor, subject to Project approval. The orbiter contractor is responsible for developing and maintaining configuration control of the ICD, using input from the instrument providers.

ICDs identify all payload interfaces, including the instrument envelope, mounting, mass, center of mass, electrical and mechanical connections, end circuits, consumption and dissipation power, pyrotechnic devices, features requiring access or clearance, purge requirements, environmental requirements, software requirements, testing, facility support, view angles and clearances, thermal control, red and green tag lists, and GSE interfaces/requirements.

Initial definition of operational timeline requirements and related resource demands (characterized by peak and typical parameters) will be documented in software-specific sections of the ICD for:

1. Volatile and non-volatile memory
2. Process activation frequency and duty cycle
3. Storage demands with storage durations

4. I/O requirements for all classes - backplane bandwidth, data bus bandwidth, command/telemetry bandwidth - including best available information on any protocol standards or unique data transfer methods are due by first preliminary ICD delivery.
5. Command and telemetry format and definition

Updated information for all items in the first delivery, with projections of final commitments for all resource demands, plus protocol specifications for all transactions using the orbiter processing resources, including behavioral characteristics of timing where it is relevant to correct operations of the science payload/mission, is due by the initial ICD date (See Table 6.4.3.a). In addition, the ICDs will contain an interface requirements verification plan.

e. GDS/MOS Requirements Documents

Ground Data System/Mission Operations System documents include:

1. Instrument Operations Processes and Procedures document
2. Inputs to the Operations Concept document
3. Inputs to the MOS/GDS Requirements document
4. Inputs to the Operations Processes and Procedures document
5. Inputs to software interface specifications
6. Inputs to operations interface agreements

f. Payload Handling Requirements and Unit History Logbook

The Payload Handling Requirements document describes any special handling necessary to ensure the safety of the flight hardware (after delivery) to the orbiter contractor and KSC. The unit history logbook accompanies the delivery of the flight hardware.

g. End Item Data Package (EIDP)

The EIDP includes, but is not limited to, final drawings, documents, mass properties, qualification data, footprint drawings, final power, final part and materials as built lists, and high resolution color photographs of the assembled instrument (with scale inserted).

6.5 Receivables

The items shown in Table 6.5.a will be conveyed to the payload provider by the Project.

Table 6.5.a MRO Payload Receivables Schedule

RECEIVABLE ITEM	DESCRIPTION	EVENT DATE OR DUE DATE
SOPC	Science Operations and Planning Computer	IDR -1 Month
S/W Updates	SOPC software updates	Annually
Electrical Connectors • EM • Flight	Orbiter-provided hardware	 Dec 02 Sep 03
Temperature Sensors • EM • Flight	Orbiter-provided hardware	 Dec 02 Sep 03

APPENDIX A – ACRONYMS

ABM	Aerobraking Maneuver
AO	Announcement of Opportunity
ATLO	Assembly, Test, and Launch Operations
C&DH	Command and Data Handling
CBE	Current Best Estimate
CDR	Critical Design Review
DSN	Deep Space Network
EIDP	End Item Data Package
EIP	Experiment Implementation Plan
ELV	Expendable Launch Vehicle
EM	Engineering Model
EMC	Electromagnetic Control
EMI	Electromagnetic Interference
EOP	Experiment Operations Plan
FMR	Financial Monthly Report
FOV	Field of View
FRD	Functional Requirements Document
FSW	Flight Software
GDS	Ground Data System
GSE	Ground Support Equipment
HGA	High Gain Antenna
HRI	High Resolution Imager
ICD	Interface Control Drawing or Interface Control Document
ICDR	Instrument Critical Design Review
IDR	Instrument Delivery Review
IEEE	Institute of Electrical and Electronic Engineers
IIM	Instrument Interface Meeting
IM	Instrument Manager
I/O	Input/Output
IPDR	Instrument Preliminary Design Review
JPL	Jet Propulsion Laboratory
GFE	Government Furnished Equipment
KSC	Kennedy Space Center
LMST	Local Mean Solar Time
LVDS	Low Voltage Differential Signaling
MA	Medium Angle or Mission Assurance
MARCI	Mars Color Imager
MCO	Mars Climate Orbiter
MIPS	Millions of Instructions Per Second
MLI	Multi-Layer Insulation
MOA	Memorandum of Agreement
MOI	Mars Orbit Insertion
MOS	Mission Operations System
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration
OTB	Orbiter Test Bed
PDMP	Project Data Management Plan
PDR	Preliminary Design Review
PDS	Planetary Data System
PI	Principal Investigator
PIP	Proposal Information Package
PIWG	Payload Integration Working Group
P/L	Payload
PMIRR	Pressure Modulator Infrared Radiometer
PRF	Pulse Repetition Frequency
PSG	Project Science Group
PSO	Primary Science Orbit
PSP	Primary Science Phase
SDT	Science Definition Team
SOPC	Science Operations and Planning Computer
SSR	Subsurface Sounding Radar
S/W	Software
SWG	Software Working Group
TAG	Target Acquisition Group
TBD	To Be Determined
TCM	Trajectory Correction Maneuver
TL	Team Leader
TMOD	Telecommunications and Mission Operations Directorate
TPR	Technical Progress Report
TTACS	Test Telemetry and Command System
TTL	Transistor-Transistor Logic
UART	Universal Asynchronous Receiver/Transmitter
UHF	Ultra High Frequency
USO	Ultra Stable Oscillator
VisNIR	Visible Near-Infrared Imaging Spectrometer
WA	Wide Angle

APPENDIX B – SUBSURFACE SOUNDING RADAR (SSR)

A Subsurface Sounding Radar (SSR) may be provided as a facility instrument to acquire data needed to determine the structure and nature of the uppermost regolith, including the possible detection of liquid water and ice layers within the first kilometer of the subsurface. In anticipation that such an instrument will fly on MRO, the following information is provided for investigators proposing to be members of a SSR facility instrument team.

B.1 Overview of the Potential MRO Facility Radar Instrument

B.1.1 Instrument Rationale

The search for water is a primary focus of Mars exploration. At the surface of Mars, water is present as ice in the polar ice caps and in trace quantities in the atmosphere. To detect liquid water on Mars today probably requires searching below the surface. As noted in the MRO SDT Report, the unambiguous detection of liquid water in the upper crust of Mars and the profiling of ice in the subsurface, particularly within one kilometer of the surface, would be major discoveries in the exploration of Mars. To that end, the MRO SDT recommended that flight of a subsurface sounding radar be considered for MRO, if the radar could confidently detect liquid water and profile ice in the topmost 1 km of subsurface with approximately 10 m vertical resolution.

A subsurface sounding radar (MARSIS) is already slated for flight on the ’03 Mars Express orbiter. That radar is designed to penetrate deep (1-5 km) into the Martian subsurface to probe the most likely location for liquid water based on current geophysical models. However, new knowledge developed from analyses of MGS data indicates that sedimentary, possibly aqueous, processes on Mars are more complex than previously anticipated. In particular, some MOC images suggest features formed by water flow linked to shallow ice/water reservoirs existing today. While a highly structured subsurface will make unambiguous detection of water difficult, the need to understand the complex interaction of processes shaping the surface and near-subsurface becomes ever more paramount.

Given the nominal characteristics of the MRO mission, the following instrument is being considered for flight on MRO and would complement the results of MARSIS on the ’03 Mars Express.

B.1.2 Instrument Concept

The subsurface sounding radar would be a radar sounder whose primary objective would be to map subsurface discontinuities and their dielectric properties in the crust of Mars. The SSR will provide two-dimensional mapping of the Martian subsurface along the ground-track and, in some areas, three-dimensional mapping can be achieved by interferometric processing of data collected over time from closely spaced orbits. (Note that there is no requirement on MRO to have the capability to fly a precisely known and controlled ground-track grid pattern.)

Instrument characteristics and performance capabilities as currently envisioned are given in the following table.

Penetration Depth	**300-1000 m**
Dynamic Range	50 dB
Central Frequency	20 MHz
Transmitted Bandwidth	10 MHz
Horizontal resolution	300–1000 m
Vertical Resolution	10–15 m
S/N	35 dB at 400 Km

The actual depth of penetration is likely to vary tremendously over the planet. Correlation of the depth and other characteristics of the radar return with surface geological and geochemical information will be important.

Transmitting at a central frequency of 20 MHz significantly reduces ionospheric propagation problems, while providing sensitivity to near surface structure and changes in composition. The 10 MHz bandwidth enables a range (depth) resolution of 15 m. The radar antenna will be a half-wavelength dipole 7-m long, with a single matching circuit for "stepped frequency" transmission. This will allow a high enough pulse repetition frequency (PRF) for clutter cancellation through Doppler filtering.

Preliminary current best estimate (CBE) mass and power budgets are reported in the following table.

	MASS (kg)	**POWER (W)**
Transmitter	3	18
Receiver	2	3
Digital Electronics	4	32
Antenna (7–m)	3	7
Total	**12**	**60**

B.2 Measurement Strategy

B.2.1 Measurement Modes

The SSR is capable of acquiring data during all orbits, regardless of illumination or ionospheric conditions, since it operates at a frequency which is much higher than the expected plasma frequency of the Martian ionosphere. However, its operation may be curtailed to prevent electromagnetic interference with the spacecraft telecom and power systems and with other instruments operating in their primary observing mode. The SSR will have a CPU capable of performing processing on board, thus greatly reducing the data volume produced by the instrument and allowing extended operation periods. However, for specialized applications, such as interferometry and verification of processing algorithms, the radar will be capable of directly providing raw data to the S/C CPU for downlink. These, then, are the two main measurement modes:

Nominal mode: A simplified coherent processing, similar to that of MARSIS, is done on board allowing data constructed from the synthesis of a number of contiguous, selectable Doppler filters to be transmitted to ground. The number of filters has not yet been selected, but the data rate will be between 5 and 75 kbps.

High rate mode: No processing is done on board. Raw data are stored and transmitted to Earth, thus allowing the application on ground of Doppler processing techniques and interferometry on adjacent orbits for enhancing subsurface detection capabilities. The expected peak data rate is 1 Mbps.

B.2.2 Data Sets and Acquisition Strategy

The processing of each sounding set will produce a one-dimensional profile of power vs. time delay of the observed portion of the Martian subsurface. Consecutive sets along the ground track will provide two-dimensional vertical sections of the Martian crust. Eventually, as overlapping observations cumulate, interferometric processing may make three-dimensional mapping of selected areas possible. In this way, global mapping of subsurface discontinuities in structure and in dielectric properties may be achieved.

APPENDIX C – ENGINEERING SUBSYTEM PERFORMANCE

Facility investigations using engineering subsystems are being solicited. In order to prepare reasonable proposals, the expected performance of the subject engineering subsystems needs to be described in sufficient detail. As neither the orbiter nor the Electra contractor has been selected, the following performance values are current best estimates and are subject to change.

C.1 Aerobraking Drag Pass Detection

The orbiter will be capable of measuring and recording the integrated (accumulated) deceleration in 1-second intervals (counts) with a maximum deceleration of 100 mm/sec/count, a quantization of 0.01 mm/sec/count, and an accuracy of 0.05 mm/sec/count (3 sigma, including errors due to bias and drift).

The orbiter will be capable of measuring and recording the attitude and attitude rates in 1 second intervals.

The orbiter will be capable of returning the deceleration data to the ground after each aerobraking pass

C.2 Ultra Stable Oscillator (USO)

The Electra telecommunication package will contain an ultra-stable oscillator with a two-channel interface to the small deep space transponder (SDST).

The stability of the oscillator is TBD [better than 1 x 10^{-11}] over 1000 seconds.